

**A DESCRIPTIVE STUDY OF LEAD ARM MUSCLE ACTIVATION PATTERNS
DURING CRICKET BATTING**

BY

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THESIS

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ABSTRACT

Introduction: Kinematic studies identify elbow extension and wrist flexion as key movements for bat swinging speed during cricket batting. Knowledge of lead arm muscle activation during cricket batting may provide a greater understanding of the mechanics leading to the generation of faster bat speed.

Aim: The current investigation aimed to determine selected muscle activation of cricketer's lead arm, maximum bat swinging speed and angular separation of the pelvis and thorax in the transverse plane (known as the X-angle) during a distance-hitting batting protocol.

Materials and Methods: 12 cricket players playing for a South African school 1st XI school team aged 16-19 years completed a distance-hitting batting protocol. Due to issues in data recording two participants' data was excluded leading to 10 participants being kept in the final analyses. Participants attempted to hit straight lofted drives while facing full-length deliveries at 80-100 km.h⁻¹ from a bowling machine. Each participant faced 12-24 balls split into overs while lead arm muscle activation, bat speed, and angle of lead-elbow flexion were recorded. Each participant's elbow and wrist flexors and extensors were monitored by electromyography (EMG) units while they batted. The EMG units were placed on the wrist flexor and extensor origins and on Triceps and Biceps Brachii. Muscle activation for each muscle was recorded in millivolts (mv) and divided by the maximum measurement of voluntary muscle activation to determine the percentage of maximum voluntary contraction (%MVC) during each shot. Percentage MVC for batting phases of backlift, downswing, contact and follow-through were averaged to compare average %MVC per muscle across all batters and obtain inter-participant variability. Lead arm elbow angle and the %MVC of the elbow and wrist muscles will be compared between successful and unsuccessful shots for analysis. Each participant's lead arm elbow angle was monitored in degrees of flexion by a goniometer placed across the anterior aspect of the elbow joint. Due to the data not having a normal distribution, non-parametric tests were used to establish the variance between dependent variables. To determine the effect of multiple groups on the independent variables a Kruskal-Wallis test for ANOVA was used. Where significant differences were identified, multiple pairwise comparisons were completed to determine where the differences occurred.

Results: Successful Lofted straight drives (32 shots) were compared to unsuccessful shots (101 shots) across all participants. Participants and batting phase were found to be significantly different for lead arm elbow angle and muscle activation however shot type was not found to be significantly different. Meaning that lead arm elbow angle and muscle activation differ based on the participant observed or based on the batting phase observed.

The backswing phase recorded a higher amount of elbow flexion (155.25°) for Lofted straight drive compared to unsuccessful shots (157.86°) and lower activation across all muscles for Lofted straight drive. The lofted straight drive had a higher amount of elbow flexion (129.52°) compared to unsuccessful shots (149.24°) for the downswing phase and muscle activation was similar with greater variation for unsuccessful shots. At contact Lofted straight drive had a higher amount of elbow flexion (153.44° v 160.13°), and higher activation in the Biceps brachii (34.61% v 28.41%) and Triceps brachii (51.07% v 43.02%). For the follow-through phase Lofted straight drives had a higher amount of elbow flexion (144.87° v 149.59°) and greater Forearm extensor activation (37.13% v 31.28%). There was a large variation across all phases (coefficient of variation between 8.79% - 70.28%) with backswing having the least variation and contact having the greatest. Meaning that the backswing phase is fairly predictable for batters and the contact phase is highly variable.

Conclusion: Muscle activation increased in the last few milliseconds before contact. The Forearm extensor had the greatest activation during the backswing and follow-through phases. During the downswing phase, Forearm flexors had the greatest activation and at contact, the Triceps brachii had the greatest activation. This study emphasizes the importance of forearm and elbow muscle for batting. Appropriate strengthening of the muscles could also help a batter execute a powerful lofted drive. Future studies with objective measures linked to batting success in prior studies can build on the importance of these findings for batter success. This study provides insight into individual batter techniques and identifies important topics for future research.

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DEDICATION

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Cricket has the second largest number of sports fans in the world with an estimated total amount of fans of between two to three billion (Das, 2020). Popularity translates to big money with the net worth of the Indian Premier League (IPL) competition reaching six point seven billion US dollars in 2019 (Pagar, 2020). Games consist of overs (period consisting of 6 balls) for either 20 overs, 50 overs, or multiple days where each team bats twice (Scanlan, Berkelmans, Vickery and Kean, 2016). The IPL is one of several annual competitions capitalizing on the most popular format of the sport, the twenty 20 (T20) format which allows each team 120 legal deliveries to score. T20 cricket results in the highest activity intensity for batters due to the need for an increased scoring rate (Petersen et al., 2009, Scanlan et al., 2016, Sholto-Douglas et al., 2020). In a cricket match, as with most sports, the team that scores more wins.

Batters attempt to score while bowlers and fielders attempt to dismiss the batter and restrict their score. Runs are scored by the batting team hitting the ball to the edge of the field, crossing the boundary, or running between the wickets (Scanlan, Berkelmans, Vickery and Kean, 2016). The highest scoring shot in cricket is a boundary which occurs when batters hit the ball to the perimeter of the field. If the ball bounces before reaching the perimeter, it is worth four runs; if the ball goes over the boundary without bouncing, it is worth six runs (Taliep and Gray, 2010). Ball carry distance is important as the higher run rate of T20 cricket results in an increase in the need for batters to hit boundaries throughout the innings (Taliep and Gray, 2010). In the 2008 IPL T20 competition the winning teams hit 20% more sixes, 14% more fours, and scored five percent fewer singles than the non-winning team (Petersen, Pyne, Portus and Dawson, 2008).

The increased importance of hitting boundaries is reflected in kinematic research on range hitting and the identification of variables linked to this (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). Significant batting mechanics for ball carry distance are ball impact location, launch angle, bat speed and resultant ball speed (Peploe et al., 2019). Ball impact location is significant for resultant ball speed indicating that players who regularly make

contact in the 'sweet spot' are more likely to be successful than batters with a high bat speed but lower impact accuracy (Peploe et al., 2019). Ball impact locations within the 'sweet spot' have a resultant ball speed reduction of less than 6% and deviations in ball direction of fewer than 10 degrees (Peploe et al., 2018).

A Stepwise linear regression found that the angular separation of the pelvis and thorax in the transverse plane (known as the X-angle), forearm extension, and wrist uncocking during downswing explained 77.7% of the difference in bat speed in male participants (Peploe et al., 2018). The combination of these variables resulted in greater range hitting which is important in hitting boundaries and increases a team's chance of winning (Peploe et al., 2019). The X-angle (angular separation of the pelvis and thorax in the transverse plane) is believed to be important as it makes effective use of the stretch-shortening cycle allowing loading and faster uncoiling during the downswing (Peploe et al., 2019). This increased rotation is believed to be a large contributor to bat speed as it allows a greater range for the upper limbs to accelerate leading to greater segmental speeds and a greater maximum bat speed (Peploe et al., 2019).

Characteristics distinguishing between more, and less, successful batters relate to superior visual systems, neuromuscular control, cognitive centres, mental aptitude, durable focus, superior physical strength, and fitness (Goble and Christie, 2016). Batters consistently modify their information processing sequences to adapt to challenges such as bowling changes, fielding changes, match status, and physical fatigue (Goble and Christie, 2016). Physical strength and fitness are believed to distinguish between two similarly skilled players (Goble and Christie, 2016).

Cricket ball carry distance was improved from a bench press training programme however this was not linked to an increase in performance (Taliep and Gray, 2010). Isokinetic strength measures of upper and lower limbs are found to distinguish between more and less successful batters (Nunes and Coetzee, 2007). Significant isokinetic strength measures indicating higher performance are internal shoulder rotation and knee flexion at high speed (Nunes and Coetzee, 2007). Baseball strength studies show the potential for improving bat velocity by using a resistance training programme (Szymanski, DeRenne, and Spanio, 2009). Medicine ball training programmes showed an increase in the rotational speed of high school baseball players which resulted in a greater bat speed (Szymanski, DeRenne, and Spanio, 2009). The medicine ball programme targets explosive trunk rotation which links to the importance of the X-angle

for bat speed generation. Improvement of bat velocity by targeting the X-angle may indicate the potential for increasing bat speed as a because of physical training.

Bat speed is generated from a multi-segmental series of levers whereby a sequential peaking of endpoint velocities from the upper limb segments would contribute to the overall bat velocity (Stretch et al., 1998). Other early kinematic studies observing front drives reported the body to move as a single unit to produce bat velocity rather than the upper limbs and bat (Elliott et al., 1993; Stuelken et al., 2005). Kinematic range hitting studies report the rotational force from a superior X-angle to generate the energy for the more distal segments such as the upper arm and wrist (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). More research is needed on bat speed generation.

Isokinetic strength studies indicate that strengthening of key muscles could improve batting hitting performance (Nunes and Coetzee, 2007). Physiological adaptations occur due to repeated movements and result in changes in morphology, functionality, levels, and rates of muscle activation (Merletti and Parker, 2004). The X-angle, elbow extension and wrist flexion are key movements for bat speed generation (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). Observing the muscle activation of the key movements may lead to a greater understanding of bat speed generation in the task of distance hitting in cricket.

The main elbow extensor is the triceps brachii and wrist uncocking is from contraction of the wrist flexor muscle group which have a common origin on the lateral epicondyle of the humerus (Alizadehkhaiyat and Frostick, 2015; Mitchel and Whited, 2022). Contraction of these agonist muscles invokes the eccentric lengthening of antagonistic muscles. The antagonistic muscles are the biceps brachii which originates on the distal anterior humerus and the wrist extensors which originate on the medial epicondyle of the humerus (Alizadehkhaiyat and Frostick, 2015, Mitchel and Whited, 2022). These muscles produce the movements important for bat speed generation as identified in kinematic studies (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021).

To observe these muscles, electromyography (EMG) can be used to measure the activation of key muscles in millivolts. By measuring the amount of activation at one moment, as a percentage of the voluntary maximum activation (in millivolts) the amount of demand at specific points can be determined in a percentage. This percentage of maximum voluntary

contraction (MVC%) over the different phases, across participants and shot types can provide a large amount of new knowledge.

Observation of a cricketer's arm muscle activation using electromyography (EMG) during a cricket batting distance hitting protocol may provide important knowledge for coaching practices and allow greater understanding of individual batter performance. Therefore, this study will be an exploratory study to analyse the lead arm muscle activation during a distance-hitting protocol.

1.2 PROBLEM STATEMENT

Bat swinging speed is a critical component of successful batting in cricket and is linked to the activation of upper limb musculature. Currently, no studies have assessed the lead arm muscle activation patterns for cricket batters. Knowledge of lead arm muscle activation can allow for targeted training to improve muscular power leading to improved bat swinging speed. For targeted training knowledge must be established.

1.3 AIMS

The study aims to characterize batter lead arm muscle activation and determine if patterns emerge. Should a pattern present across all participants, this may indicate that a common magnitude of the dependent variables is required to successfully execute the independent variables. Should a pattern present within each participant's samples this may indicate that there are not individual differences based on unique batter technique for the current sample. To do this the objectives are:

- 1.** Compare batter lead elbow angle and arm muscle activation patters, X-angle and maximum bat speed across all samples to see if there is a relationship for shot type.
- 2.** Compare batter lead elbow angle and arm muscle activation patters, X-angle and maximum bat speed across all samples to see if there is a relationship for each shot phase.
- 3.** Compare batter lead elbow angle and arm muscle activation patters, X-angle and maximum bat speed across all samples to see if there is a significant difference between participants.

1.4 RESEARCH HYPOTHESES

1. Lead arm elbow angle and/or muscle voluntary contraction percentage will not differ between shot types across all participants.

Ho: $\mu\text{MVC}\% \text{Shot}(1) = \mu\text{MVC}\% \text{Shot}(n)$ ($p \geq 0.05$).

Ha: $\mu\text{MVC}\% \text{Shot}(1) \neq$

$\mu\text{MVC}\% \text{Shot}(n)$ ($p \leq 0.05$).

2. Lead elbow angle and/or muscle voluntary contraction percentage will not differ between participants.

Ho: $\mu\text{MVC}\% \text{Participant}(1) = \mu\text{MVC}\% \text{Participant}(n)$ ($p \geq 0.05$).

Ha: $\mu\text{MVC}\% \text{Participant}(1) \neq \mu\text{MVC}\% \text{Participant}(n)$ ($p \leq 0.05$).

3. Lead arm elbow angle and/or muscle voluntary contraction percentage will not differ between batting phases across all participants.

Ho: $\mu\text{MVC}\% \text{Phase}(1) =$

$\mu\text{MVC}\% \text{Phase}(2) = \mu\text{MVC}\% \text{Phase}(3) = \mu\text{MVC}\% \text{Phase}(4)$ ($p \geq 0.05$).

Ha: $\mu\text{MVC}\% \text{Phase}(1) \neq$

$\mu\text{MVC}\% \text{Phase}(2) \neq \mu\text{MVC}\% \text{Phase}(3) \neq \mu\text{MVC}\% \text{Phase}(4)$ ($p \leq 0.05$).

- MVC%: Percentage of muscle voluntary contraction.
- n: sample of all participants
- Ho: Null hypothesis
- Ha: Alternate hypothesis

1.5 OUTLINE OF THESIS

Chapter one began with an introduction of cricket and cricket batters leading to a problem statement identifying a gap in the literature. This is refined into the purpose of the study with specific aims and objectives outlined.

Chapter two looks at the literature that shows the need for certain characteristics to be a successful cricket batter, with physical strength being linked to ball carry distance and bat speed generation. The process of movement related to bat speed generation is understood and this study aims to detail the process of the muscle activation behind that movement.

Chapter three contains the methodology used to do this by repeating a previous protocol and using statistical analyses to determine if patterns exist depending on the shot played, the phase of the shot and the individual participant's technique.

Chapter four details the results of the study according to the shot played, the phase of the shot determines the differences across all participants and the differences within each participant's results.

Chapter five discusses the results to compare them to prior studies, describe what was measured and determine if patterns do exist that may be important for further research. Batter lead arm elbow angle can be compared to prior studies however no other studies to the authors knowledge have measured lead arm muscle activation.

Chapter six details the limitations of the study, identifies future recommendations for research and finishes with a conclusion to summarize the findings.

CHAPTER 2

LITERATURE REVIEW

2.1 CRICKET AS A SPORT

Cricket is a game of two teams of 11 players, formally played on a circular field involving the activities of bowling, batting, and fielding within a specific time frame (Scanlan, Berkelmans, Vickery and Kean, 2016). The goal is to score more runs than the other team or restrict the other team to a lower score. Runs are scored by the batting team hitting the ball to the edge of the field, crossing the boundary, or running between the wickets (Scanlan, Berkelmans, Vickery and Kean, 2016). Amongst other methods, the bowler delivers the ball attempting to dismiss the batter by hitting the stumps or getting him out caught by the fielders (Scanlan, Berkelmans, Vickery and Kean, 2016). The common ways a batter can be dismissed by the bowler is either by hitting the wickets or hitting the batsman's leg before the wicket; or by the fielder throwing at and hitting the wickets while the batter is running or catching the ball before it hits the ground (Scanlan, Berkelmans, Vickery and Kean, 2016).

The other 10 players of the bowling team are the fielders who attempt to prevent the batter from scoring by stopping the ball from crossing the boundary or dismissing the batsman (Scanlan, Berkelmans, Vickery and Kean, 2016). There are two batters on the field at any time until 10 of the batters have been dismissed or the number of overs is reached at which point the innings/game is over (Scanlan, Berkelmans, Vickery and Kean, 2016). Games consist of overs (period consisting of 6 balls) for either 20 overs, 50 overs, or for multiple days where each team bats twice (Scanlan, Berkelmans, Vickery and Kean, 2016).

2.2 CHARACTERISTICS OF SUCCESSFUL CRICKET BATTERS

Characteristics distinguishing between more and less successful batters relate to superior visual mechanism, neuromuscular control, cognitive centre processing, mental aptitude, concentration ability, appropriate physical strength and fitness (Goble and Christie, 2016).

2.2.1 Visual system

Superior visual systems allow batters to observe pre-delivery cues from the bowler or field placements (Goble and Christie, 2016; Stretch et al., 2000). Observing fielding placements helps the batter to assess the bowler's delivery and wicket-taking strategies (Goble and Christie, 2016, Mann, Abernethy and Farrow, 2010; Sarpeshkar and Mann, 2011). Observing the orientation of the ball in the bowler's hand before release indicates the type of delivery, observing arm orientation and the height of ball release informs the potential line and length of the delivery (Goble and Christie, 2016; Sarpeshkar and Mann, 2011).

Once the delivery occurs batters can follow the flight of a delivery and react to any deviations (Goble and Christie, 2016, Sarpeshkar and Mann, 2011). Following ball release, the first 50-80% of ball flight is tracked informing an anticipatory saccade that moves the batter's focus to where they predict the ball will bounce (Goble and Christie, 2016, Land and McLeod, 2000). Good visual scanning methods allow batters to process this information faster and more efficiently providing greater opportunities to intercept the ball (Goble and Christie, 2016, Mann et al., 2010).

Spatio-temporal demands

Fast bowlers deliver the ball at speeds between 30-40 m.s⁻¹ which allows batters approximately 500 ms from the time of release to the ball reaching the wickets (Worthington et al., 2013). Batters must make contact with the ball moving at three to four centimetres per millisecond and potentially swinging in the air or deviating off the pitch. Human visual and physical movement capabilities of 200 milliseconds and 700 milliseconds are not capable of intercepting these fast deliveries (Abernethy, 1981). Due to the extreme temporal constraint batters require coping mechanisms such as anticipation (Peploe et al., 2018).

2.3 STRENGTH STUDIES

Due to the high physical demands of batting players require a high level of strength and physical fitness to perform over extended periods. Strength of upper and lower limbs have been found to discriminate between more and less successful batters (Nunes and Coetzee, 2007). The other undetermined factors may refer to the cognitive centres and information processing systems mentioned among the characteristics of successful batters (page nine).

Knee flexion/extension variables contributed 57% to the ranking of batters in comparison to other factors and shoulder internal/external rotation strength variables contributed 61% (Nunes

and Coetzee, 2007). Knee extension variables comprised the majority (45%) of these predictive measures indicating a need for greater quadriceps strength (Nunes and Coetzee, 2007).

The shoulder rotation strength variables were a high internal rotation to external rotation ratio, weaker stabilizing around a joint, left internal rotation average power at high speed and left internal rotation torque at slow speed (Nunes and Coetzee, 2007). A high internal rotation to external rotation ratio possibly indicates greater glenohumeral stability of the shoulder and lower injury risk resulting in more regular play over longer periods (Nunes and Coetzee, 2007). Weaker stabilizing around a joint indicates an “inefficient length/tension relationship leading to interference with optimal firing patterns of the primary movers during rapid concentric and eccentric contractions that occur during different movements” (Nunes and Coetzee, 2007). Left internal rotation average power at high speed is possibly due to the need for explosive backlift when playing attacking shots (Nunes and Coetzee, 2007). Left internal rotation torque work at low speed is possibly due to the need for greater endurance to ensure that the correct backlift pattern will occur avoiding errors (Nunes and Coetzee, 2007). Patterns of movement resulted in greater performance indicating a potential optimum technique leading to success.

Baseball studies used electromyography and determined that strengthening the lead arms triceps brachii (long head) would increase the force that batters could transfer to the bat (Kitzman, 1964). This is relevant to cricket due to the importance of lead arm elbow extension for generating bat speed whereby the triceps brachii is a main elbow extensor (McErlain-Naylor et al., 2021). The activation pattern in baseball batters is activation of the lower body followed by the rear arm pectoralis major, then the lead arm latissimus dorsi followed by the lead arm triceps brachii (Reyes et al., 2011). The upper body muscles began activating in the ‘early’ phase which would correlate to the stride phase in cricket (Reyes et al., 2011). The triceps brachii continued to have a high level of activation until the follow-through phase indicating its role in lead arm extension to exert force upon the ball (Reyes et al., 2011). Training programs targeting these muscles increased ball carry distance, possibly due to an increased ability to exert force upon the ball. Ball carry distance increased as a result of the bench press training program however this did not correlate to an increase in performance (Taliep and Gray, 2010).

The small amount of information on upper limb muscle activation indicates the need for high-speed explosive strength because of the unique technique of cricket batting (Nunes and Coetzee, 2007). There is also the need for endurance as the muscles are required to maintain

the correct positions and sequences of movement throughout the innings (Nunes and Coetzee, 2007). This understanding occurs from the knowledge of the end product of strength adaptations and does not consider the mechanisms responsible for this (Nunes and Coetzee, 2007). Physiological adaptations occur due to repeated movements and result in changes in morphology, functionality, levels and rates of muscle activation (Merletti and Parker, 2004). Identification of key repeated movements allows for better preparation and improved performance. Understanding the lower limb internal muscular activation allows coaches to prepare players for the demand of sprinting between the wickets and maintaining a stable base when batting (Christie et al., 2018). Greater knowledge of upper limb muscle activation can allow for better preparation of players.

The lack of upper limb muscle activation studies prevents coaches from identifying or preparing players for the demands they are facing and is a gap in cricket literature. To establish what may be important to describe in upper limb muscle activation, it is important to look at the orientation of batters to determine which muscles will be key in the batting technique of modern cricketers.

2.4 KINEMATICS OF CRICKET BATTERS

Studies on the kinematics of the front foot drive indicate common movement positions amongst cricket batters and a general 'correct' technique. The batting technique is derived from coaching literature (The MCC, 1954; Woolmer, 1993; Tyson, 1994; Australian Cricket Board, 2001) and biomechanical studies (Abernethy, 1981; Davis, 1983; Gibson and Adams, 1989; Elliott et al., 1993; Tyson, 1994; Stretch et al., 1998; Glazier, Davids and Bartlett, 2002; Stuelcken, Portus and Mason, 2005; Taliep, Galal and Vaughn, 2007). The guide is based upon right-handed batters and it is believed that the same would apply to left-handed batters.

Kinematic studies increased understanding of professional batters' technique, evolving to become more representative of game conditions. Elliott et al, (1993) analyzed two on-drives and two off-drives by ten Western Australian state batters on a turf pitch and reported a mean delivery speed of $20.7 \text{ m}\cdot\text{s}^{-1}$. Stretch et al, (1998) analyzed the best singular front-foot drive and best singular front-foot defensive of fourteen A and B division South African provincial batters on a turf pitch. Stuelcken, Portus and Mason, (2005) analyzed nine front-foot off-side drives by nine international batters over 18 months in state or international matches in Australia and

measured a mean delivery speed of $30.4 \text{ m}\cdot\text{s}^{-1}$. Taliep, Galal and Vaughn, (2007) analyzed ten half-volley drives from ten provincial and ten club batters whilst facing a virtual bowler. These methods are less representative of match conditions and show differences to later studies with lower lead elbow flexion and greater rear elbow flexion during the downswing phase, than McErlain-Naylor et al (2021) in Table 4.

McErlain-Naylor et al, (2021) analysed the range hitting of 15 males (age 21 ± 3 years, height $1.83 \pm 0.05\text{m}$, mass $80.4 \pm 9.3\text{kg}$) and 15 females (age 20 ± 3 years, height $1.71 \pm 0.05\text{m}$, mass $68.6 \pm 7.4\text{kg}$) batters. Peplow et al, (2018) measured a mean release speed of $32.4 \text{ m}\cdot\text{s}^{-1}$ that was reduced to $25.2 \text{ m}\cdot\text{s}^{-1}$ after the ball bounced. McErlain-Naylor et al, (2021) measured a mean release speed of $25.7 \text{ m}\cdot\text{s}^{-1}$ that was reduced to $20.1 \text{ m}\cdot\text{s}^{-1}$ after the ball bounced. The more representative methods measured higher bat speeds and expanded on previous literature with a greater array of information recorded. Expanding on prior methods to add to knowledge can lead to a greater understanding of the complex picture of cricket batting.

When facing a bowling machine batters demonstrate lower backlift heights, shorter stride lengths, downswing delays (80-100 ms) and slower bat speeds ($10.62 \text{ m}\cdot\text{s}^{-1}$ v $11.38 \text{ m}\cdot\text{s}^{-1}$) due to a lack of pre-release assessment (Pinder et al., 2011). Pre-release information allows batters to predict the length of a delivery (Pinder et al., 2011, Renshaw et al., 2007). “A key feature of striking actions is the development of stable movement organization (Renshaw et al., 2007). However, the studies used different surfaces, delivery methods and delivery speeds which resulted in temporal and coordinative differences (Pinder et al., 2011, Renshaw et al., 2007).

The different factors affect how representative a study is and can influence the results of a study or lead to incorrect conclusions (Connor, Farrow and Renshaw, 2018). Due to crickets' dynamic nature, it is highly difficult to ensure a repetitive, controlled testing procedure and thus it is important to consider how this may affect the results. From the kinematic studies, the different testing conditions are either from match situations, which makes the information very relevant for that context or from a simulated scenario with limited application to live matches. The lab-based testing is done to ensure the reliability, validity and repeatability of the study (Connor, Farrow and Renshaw, 2018). Greater research is needed on cricket batting kinematics, repeating the protocol of prior studies with adaptations to add greater information, will expand the limited literature in the field.

Summary of kinematic study findings

Shot timing

For Elliott et al, (1988) downswing was 0.36s before impact, Stuelken, Portus and Mason, (2005) measured the downswing at 0.16s before impact and Stretch et al, (1998) measured it as 0.21s before impact (Table 3). Stretch et al, (1998) measured the Stride as 0.58s before impact (Table 4).

Table 1

Summary of Kinematic studies on the Stance phase

BATTING STANCE			
Study	Stance	Orientation	Initial movement
Stretch et al, (1998)		Lead knee and hip over the lead foot. Rear knee (0.05m), hip (0.07m) and shoulder (0.09m) forward of the rear foot. Lead shoulder 0.08m forward of a lead foot and 0.07m higher than rear shoulder. COM 0.08m ahead of midline between the feet. Front elbow=137°, back elbow=140°, front knee=173° and back knee=167°.	
Stuelcken, Portus and Mason, (2005)	0,46m	Front shoulder (0,07m) higher than rear shoulder and positioned over the front foot, COM over midpoint. Shoulder alignment 26°.	7/9 Move rear foot backwards with all but one moving to the off side.
Taliep, Galal and Vaughn, (2007)-skilled		Front shoulder 0.078m forward of the lead foot, head 0.155m forward of the centre base point. Hip angle=12°, shoulder angle=15°.	7/10 skilled batters have initial movement. 7/9 of all initial movements move the rear foot backwards and to off side.
Taliep, Galal and Vaughn,		Front shoulder 0.072m forward of lead foot, Head 0,09m forward	2/10 less skilled batters have initial movement. 7/9 of all initial movements move the

(2007)- unskilled		of the centre base point. Hip angle = 11°, shoulder angle= 19°.	rear foot backwards and to off side.
Peploe et al, (2018)	0.52m	Stance width = 170 ± 36% of player shoulder width. COM forward of the midline, on average 63± 9% of the distance from front foot to back foot. Open batting stance as sternum and thorax = 68° about global vertical axis. Thorax flexed forward 40 ± 8°. Front knee =142° and back knee =147°. COM height = 0.98m. The front knee (0.007 ± 0.040 m), front shoulder (0.011 ± 0.072 m), and a virtual point between the eyes (0.002 ± 0.075 m) are forward of the front foot. The virtual point between eyes (0.063 ± 0.073m) outside the line of the middle stump (towards the offside) in the global mediolateral plane.	15/29 batters had a trigger movement. 5 moved both feet back and towards the off stump. 4 moved their rear foot back and across before initiating a forward press, and 4 moved their rear foot forward before forward stride. 1 initiated only a forward press and 1 moved the rear foot back and across before the forward stride.

COM is an abbreviation of centre of mass

Stance

Batter stances have been measured as wider than the coaching recommendations, believed to be due to greater weight distribution to quickly move to react to delivery length (Stuelcken, Portus and Mason, 2005, Peploe et al., 2018; Table 1). Studies, where the batter is aware of the delivery length to be faced, are limited in validity as batters move their COM forward in anticipation of full-length deliveries (Peploe et al., 2018). From the start of the stance phase until the ball releases batters flexed their knees and hips, dropping their COM (Peploe et al., 2018).

Table 2*Summary of Kinematic studies on the Backlift phase*

BACKLIFT			
Study	Backlift Angle	Backlift height	Orientation
Elliott et al, (1993)			121° for front elbow, 76° for back elbow, 160° front knee, 144° back knee, 104° trunk.
Stretch et al, (1998)		Bat COM = 0.74m	144° for front elbow, 34° for back elbow
Stuelcken, Portus and Mason, (2005)	40°- 47°	1.53m	The front elbow is at 109° and the back elbow at 58°. Lead shoulder dipped by 0.16m resulting in a trunk alignment of 68° from the ground. Hip angle (start) = 25°, hip angle (end) =35°, shoulder angle (start) = 27°, shoulder angle (end) =9°.
Taliep, Galal and Vaughn, (2007)-skilled	26,3°- 27,3°		Head COM moved 0.207m forward. Hip angle = 27°, shoulder angle= 17°.
Taliep, Galal and Vaughn, (2007)-unskilled	26,3°- 27,3°		Head COM moved 0,13m forward. Hip angle = 25°, shoulder angle= 11°.
Peploe et al, (2018)	-16 ± 11°, to -8 ± 8°. average = -12 ± 10°	Bat COM = 1.128m	Bat angle X (bat angle about the global mediolateral axis) = -109 ± 23° at the start to 149 ± 13° at the peak. Bat angle Z (bat angle about the global vertical axis.) = -20 ± 18° at the start to -33 ± 19° at the peak. Thorax flexed forward 11°from -43 ± 9° to -54 ± 6°. Back shoulder (-21 ± 10° extension, -9 ± 7° adduction). Front shoulder (-3 ± 10° flexion, -19 ± 10° adduction)

Backlift

Historic coaching recommendations have advocated for a straight backlift with the bat in line with the wicketkeeper (Penn and Stafford, 2012; Table 2). Recent research shows that 81 of the 95 professional batters they observed use a lateral backlift technique rather than a straight backlift (Noorbhai and Noakes, 2016). The lateral batting technique is more common at the highest levels of the game and is associated with greater performance (Noorbhai and Noakes, 2016). The looped backlift is where the bat is angled further than the conventional 25° from the centre of the pitch and loops from a wider angle until it is brought back to parallel with the shoulders (Stuelcken, Portus and Mason, 2005).

Kinematic studies that have measured the mean backlift angle have found a mean of lateral backlift technique (Taliep, Galal and Vaughn, 2007; Peplow et al., 2018). A looped backlift path has a quicker downswing time due to the mechanical advantage of the wrist being close to the COM, allowing a large amount of torque of the bat around the wrist using minimal muscular effort (Stuelcken, Portus and Mason, 2005).

Table 3

Summary of Kinematic studies on the Stride phase

STRIDE	
Study	Orientation
Gibson and Adams, (1989)	The front foot was flat 0,133s before impact.
Stretch et al, (1998)	The stride begins at 0.58s and the downswing occurs at 0.36s before impact with the ball. Stride time of 0.52s, stride distance of 0.68m. The front foot was flat 0.06s. Front elbow=127°, back elbow=102°, front knee=152° and back knee=145°.Head dropped 0.12m and moved forward 0.35m.
Stuelcken, Portus and Mason, (2005)	Front stride occurred 0.38s before impact in match conditions. Stride time of 0.33 ±0.12s, stride distance of 0.35 ±0.22m long. The front foot was flat 0,05s before impact. At 0.08s before impact, the COM moved forward by 0.07m.

Stride

Prior studies suggest the batter delays front foot movement and the downswing to gain as much flight information as possible before making contact to adjust to any deviations (Abernethy, 1981; Abernethy and Russell, 1984; Gibson and Adams, 1989; Taliep, Galal and Vaughn, 2007; Table 3). Batters flex at the knee during the stride to provide a stable base and shift the weight into the shot but due to time constraints, it must overlap with the downswing (The MCC, 1954; Stretch et al., 1998; Stuelcken, Portus and Mason, 2005). The forward step has a large influence on the bat's speed and may contribute more than the upper limbs (Elliott et al., 1993; Stuelcken, Portus and Mason, 2005). This contradicts the prior belief that “the upper limbs move in a sequential chain as the shoulder, elbow and wrist flex to generate the greatest speed at the distal point of the bat” (Stretch et al., 1998).

Table 4

Summary of Kinematic studies on the Downswing phase

DOWNSWING		
Study	Bat speed	Orientation
Elliott et al., (1993)	15,22 m·s ⁻¹	The time of downswing to impact was 0,36s. Trunk alignment=85°.
Stretch et al., (1998)	11,8 m·s ⁻¹	The time of downswing to impact was 0,21s. Head dipped 0.09m at 0.06s before impact. Front elbow=117°, back elbow=107°, front knee=149° and back knee=165°.
Stuelcken, Portus and Mason, (2005)	16 m·s ⁻¹	Time of downswing to impact was 0,16s.
Taliep, Galal and Vaughn, (2007)- skilled	11,5 m·s ⁻¹	
Taliep, Galal and Vaughn, (2007)- unskilled	10,7 m·s ⁻¹	
Peploe et al., (2018)	28.4 ±2.5 m·s ⁻¹	Bat angle=-167.4°, Bat COM height=1.24m, Wrist cocking angle=119.3°, Lead elbow=121.2°, Rear elbow=56.1°, lead elbow extension=29.7°, rear elbow extension=70.2°, X factor (transverse) =17.6°, X' factor (frontal) =22.3°.

McErlain-Naylor et al., (2021)	22.6 ±2.3 m·s ⁻¹	Bat angle=-164°, Bat COM height= 1.21m, Wrist cocking angle= 118.7°, Lead elbow=133.7°, Rear elbow=65.4°, °, lead elbow extension=-3°, rear elbow extension=47.1°, X factor (transverse) =12.4°, X' factor (frontal) =14.3°.
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Downswing

A shorter downswing has the advantage of the batter having more time to assess ball flight information before executing the shot (Abertnethy, 1981; Table 4). The smaller arc of the looped backlift allowed a quicker execution to help the spatio-temporal constraints of facing fast bowlers (Stuelcken, Portus and Mason, 2005). Batters need accurate shot placement to guide the ball into a gap and require high bat speed to impart enough force for the ball to reach the boundary (Stuelcken, Portus and Mason, 2005). This is seen where the Figure Nine position is advocated. This is where the high lead elbow and the lower arm are moving together which forms a figure nine with the bat. Maintaining the Figure Nine position and moving the upper limbs in unison results in higher accuracy while the force is generated by the forward step and momentum of leaning into the shot (Stuelcken, Portus and Mason, 2005). This is in line with the coaching literature (Tyson, 1994; Australian Cricket Board, 2001).

Table 5

Summary of Kinematic studies on the Impact and Follow-through phases

IMPACT	
Study	Orientation
Elliott et al., (1993)	Front elbow=136°, back elbow=115°, front knee=140° and back knee=145°, trunk=85°, bat angle=69°, point of impact was 0.03m behind the front ankle and 0.22m in front of the head.
Stretch et al., (1998)	Front elbow=124°, back elbow=98°, front knee=147° and back knee=145°.
Taliep, Galal and Vaughn, (2007)-skilled	COM moved 0,236m forward of the centre base. Hip angle = 35°, shoulder angle= 47°.
Taliep, Galal and Vaughn, (2007)-unskilled	COM moved 0,199m forward of the centre base. Hip angle = 45°, shoulder angle= 48°.

Stuelcken, Portus and Mason, (2005) Front knee=147°, front elbow=116°, rear elbow=98° hip angle = 42°, shoulder angle= 40°, trunk angle=91°, bat angle=68°, head was 0.05m behind impact and impact occurred 0.22m behind the front ankle.

Peploe et al., (2018) Bat angle=21°, wrist cocking=162.1°, wrist uncocking =57.5°, lead elbow=150.9°, rear elbow=126.3°, pelvis transverse=-5.1°, thorax transverse=-6.7°, X factor reduction (max) =23.3°, X' Factor reduction (max) =19.3°, COM A-P displacement (min) =0.37m, lead knee angle=141.6°, base length=0.81m.

McErlain-Naylor et al., (2021) Bat angle=16.8°, wrist cocking=168.9°, wrist uncocking =61.9°, lead elbow =130.8°, rear elbow=112.5°, pelvis transverse=-3.9°, thorax transverse=-4.0°, X factor reduction (max) =19.6°, X' Factor reduction (max) =17.4°, COM A-P displacement (min) =0.46m, lead knee angle=146.1°, base length=0.82m.

FOLLOW THROUGH

Study	Orientation
Stretch et al., (1998)	Front elbow=125°, back elbow=132°, front knee=150° and back knee=139°.
Stuelcken, Portus and Mason, (2005)	All nine international batters used an abbreviated or 'checked' follow-through.
Taliep, Galal and Vaughn, (2007)-skilled	Heads were 0.31m forward of the centre base point.
Taliep, Galal and Vaughn, (2007)-unskilled	Heads were 0.22m forward of the centre base point.
Peploe et al., (2018)	Ball launch speed=33.5±2.6 m·s ⁻¹ , ball carry distance= 80.7±10m.
McErlain-Naylor et al., (2021)	Ball launch speed=27.3±1.3 m·s ⁻¹ , ball carry distance=57.7±8.8m.

Follow through

The initial thought was that batters need to follow through fully to decelerate over time and prevent submaximal force applied to the ball from premature deceleration (Stretch et al., 1998; Table 5). Higher speeds at the distal part of the bat indicated that the force applied upon the ball was not altered due to the 'checked' follow-through (Stuelcken, Portus and Mason, 2005).

A checked follow-through is when batters continue to raise the bat following impact but do not place the bat over or behind the lead shoulder (Stuelcken, Portus and Mason, 2005).

2.5 DISTANCE HITTING KINEMATICS

Batting kinematics have looked to understand key movement patterns in the forward drive and forward defensive shots in cricket (Elliott et al., 1993; Stretch et al., 1998; Stuelcken, Portus and Mason 2005; Taliep, Galal and Vaughn 2007; Peplow et al., 2018). In modern cricket, a major contributor to success is the ability of batsmen to clear the boundary (Taliep and Gray, 2010; Peplow et al., 2018). In the 2008 IPL T20 competition the winning teams hit 20% more sixes, 14% more fours and scored 5% fewer singles than the non-winning team (Petersen, Pyne, Portus and Dawson, 2008). With the increased importance of distance hitting in cricket, kinematic studies turned to identifying the key movement patterns contributing to increased range hitting.

Key determinants of ball carry distance were identified as ball impact location, vertical ball launch angle, ball launch speed and maximum bat speed (Peplow et al., 2018). Through motion capture analysis the key kinematics affecting each of the determinants can be identified and the extent of their influence estimated through regression models (Peplow et al., 2018). The regression models accounted for 67.6% of the variation in ball launch speed, 82.5% of the variation in vertical ball launch angle and 77.7% of the variation in maximum bat speed (Peplow et al., 2018). Vertical ball launch angle is due to the bat angle about the global mediolateral axis at the time of impact (Peplow et al., 2018). Ball launch speed is due to bat speed at impact and impact location in the mediolateral and longitudinal directions (Peplow et al., 2018). Impact location in the mediolateral and longitudinal direction explained 43.1% of the variation of ball launch speed, meaning impact location is the major contributor identified (Peplow et al., 2018). Variation in bat speed is due to the X-factor at the commencement of the downswing, lead elbow extension and wrist uncocking during the downswing (Peplow et al., 2018).

The X-factor at the commencement of the downswing accounted for 28% of bat speed variation making it the greatest identified contributor (Peplow et al., 2018). Lower limb kinematics were not included so the belief that the forward step has a large influence on the bat speed and may contribute more than the upper limbs cannot be proved (Elliott et al., 1993; Stuelcken, Portus and Mason, 2005).

Another kinematic study on distance hitting measured the kinematics of 15 female cricket batters to compare the differences between genders (McErlain-Naylor et al., 2021). The three major contributors to bat speed were measured and compared, with women having less magnitude X-factor at the commencement of the downswing and less magnitude elbow extension during the downswing than men (McErlain-Naylor et al., 2021). X-factor is the separation between the pelvis and thorax segments in the transverse plane (McLean, 1992). Unique kinematics found across the female participants are a flexed lead elbow during the downswing, greater wrist uncocking (although not statistically significant for bat speed), lower bat angle about the global mediolateral axis at impact and a lower rear elbow angle at impact (Peploe et al., 2021). As a result of the different kinematics women were found to have lower maximum bat speeds, ball launch speeds and ball carry distance (McErlain-Naylor et al., 2021). The cause of the differences is likely to be multifactorial, involving aspects relating to individual players, their equipment, the task of range hitting in male and female cricket and the history of training experience and coaching practices (McErlain-Naylor et al., 2021).

The limited research on cricket batting indicates the importance of physical strength and the link it has with ball carry distance which has been linked to bat speed generation (Nunes and Coetzee, 2007; Taliep and Gray, 2010; Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). Ball carry distance was improved from a training program however this did not result in improved performance so greater knowledge is needed on the muscles to be targeted in bat speed generation (Taliép and Gray, 2010). Baseball studies used EMG to identify the activation timing and the magnitude of activation in a shot (Kitzman, 1964; Reyes et al., 2011). They found that the triceps brachii is important due to its role in lead elbow extension which is important for bat speed activation in cricket (Kitzman, 1964; Reyes et al., 2011; Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). This indicates the need for greater knowledge of the muscles used in cricket bat speed generation by determining the muscles used and the demands of those muscles in bat speed generation.

"Electromyography (EMG) is an experimental technique concerned with the development, recording and analysis of myoelectric signals" (Konrad, 2006). Therefore, as the batters perform their shots, variations occur in the muscle fibers as the batters move which causes variations in the myoelectric signals of the muscles. These myoelectric signals are recorded to determine information about muscle activation (Konrad, 2006). The information EMG can provide is whether the muscle is active to determine when activation occurs, the magnitude of

activation to determine if the muscle is more or less active than another muscle or at another time and if the muscle is fatigued (Konrad, 2006).

Electromyography may use invasive means through needles placed into the muscle or non-invasive means through surface electrodes (Konrad, 2006). Whereas needle electromyography produces less noise and has a higher accuracy it is highly invasive, particularly for dynamic movements (Konrad, 2006). Due to its non-invasive nature surface electromyography is favored in kinesiological studies and is referred to as surface electromyography (SEMG). Surface electromyography can detect a large volume of muscle unit action potentials from the most superficial motor units (Merletti and Parker, 2004). A motor unit consists of many muscle fibres and so SEMG detects the magnitude of all monopolar action potentials of innervated fibres in the motor units (Konrad 2006). This is one of the limitations of SEMG as it is very difficult to isolate the muscle of interest or separate the muscles measured (Konrad, 2006). Other limitations are comparing subjects and the relation of muscle activity to muscle force (Konrad, 2006).

To compare muscle activation a process of normalisation occurs by recording maximal voluntary contraction through a standard movement and representing muscle activation throughout the test as a percentage of this maximum (Konrad, 2006). The standard movement can be isometric or static such as a leg extension against a stationary pad or dynamic such as the maximal activation during a task such as sprinting (Konrad, 2006). The advantage of isometric or static normalization is that muscle force can be measured with muscle activation however the application of this is limited to isometric activities exactly replicating the testing procedure (Konrad, 2006). The advantage of dynamic normalization is the applicability of findings to dynamic applications and it has been shown to have a high level of repeatability, reliability and sensitivity (Albertus-Kajee, 2011). For comparison of dynamic movements such as a cricket batting shot, clearly defined movement phases must be established such as the phases of the shot. Comparison of batter muscle activation over the different phases of a shot will provide greater knowledge of the demands placed upon the batters.

2.6 SUMMARY OF CHAPTER

Upper limb strength differences in cricket batters have been found to have a greater impact on distinguishing between batter performance than lower limb strength differences (Nunes and

Coetzee, 2007). There are few studies on cricket batter upper limbs. Kinematic studies have determined the magnitude of lead elbow extension, X-angle and wrist flexion to be key in the generation of bat speed which is important for batter performance (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). Baseball EMG studies increased knowledge of muscle activation in generating bat speed (Kitzman, 1964; Reyes et al., 2011).

There are no studies to the author's knowledge on muscle activation of the upper limbs of cricket batters, indicating a gap in the literature. Observing and recording lead arm muscle activation may identify information in the generation of bat speed in the task of distance hitting in cricket. This thesis will be an observational descriptive study of lead arm muscle activation during a simulated distance-hitting protocol.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH DESIGN

The study was an explorative descriptive case study observing muscle activation of the batter's lead arm during a distance-hitting protocol adapted from prior kinematic studies (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). Participants from a school in Makhanda, Eastern Cape, South Africa replicated a distance-hitting protocol that established the kinematic variables important for bat speed generation to measure muscle activation.

3.2 ETHICAL CONSIDERATIONS

Before the study, ethical approval was obtained from the Rhodes University Ethical Standards Committee (RUESC) with the departmental tracking number HKE-2018-04 and the RUESC reference number 10750088. All players gave their written, informed consent indicating their willingness to be tested (Appendix one). Permission was also granted by the team coaching staff, school authorities and parents or guardians of minors.

3.3 PARTICIPANTS

The sample was a sample of convenience of 12 adolescent batsmen from a Makhanda, Eastern Cape, South Africa school.

Inclusion criteria:

Participants were male batters aged 16-19 years playing competitive cricket from years 2022 and 2023 nominated by coach as a specialist batter, free from any medical condition and consenting to the study.

Exclusion criteria:

Due to the need to perform shots aiming for maximal ball carry distance, participants who had any current or previous medical condition which prevented them from testing were excluded. These included match time loss, general time loss, medical attention, and player-reported and imaging abnormality injuries (Orchard, Kountouris and Sims, 2016).

3.4 VARIABLES

Independent variables:

- Participant.
- Batting phase.
- Shot type.

Participants were selected as an independent variable to determine if there were differences in the dependent variables due to individual differences. This determined whether an individual approach was needed for cricket batters.

The batting phase was selected as an independent variable to determine if there were differences in the dependent variables due to different demands in each phase of the cricket batting shot. Providing greater information and adding to the literature on cricket batting.

The shot type was selected as an independent variable to determine if there were differences in the dependent variables based on the shot type performed. This added to the literature on cricket batting by broadening the application of the study findings to include prior kinematic and biomechanical studies that have observed the straight drive and cover drive shots.

Dependant variables:

- Muscle activation.
- Lead elbow angle (degrees).
- Bat speed ($\text{m}\cdot\text{s}^{-1}$)
- Angular separation of the pelvis and thorax in the transverse plane (X-angle).

Fixed variables:

- Ball delivery speed.
- Ball delivery location.

3.5 PROTOCOL

Pilot trial:

The pilot trial aimed to establish the testing protocol and refine the data processing before actual experimentation. A volunteer from the department faced several throw downs whereby the ball was thrown to the volunteer in the department while adjustments were made. The ball was thrown from the tester to mimic a delivery from a bowler at a lower speed rather than a bowling machine as the goal was to test the protocol and not emulate match conditions.

To measure the X-angle three Optitrack soft markers (Corvallis, Oregon, USA) were fitted on the seventh Cervical (C7) vertebrae and the medial superior spine of the left and right scapulae. Eight cameras (Optitrack Prime 17W) were used, measuring at variable speeds to determine the best frequency for accurate data recording. Marker occlusion (due to the limited number of cameras available within the department) prevented accurate data recording. Due to marker occlusion and inaccurate data recording the motion capture analysis was excluded from testing. This was thus a limitation of this study that will be expanded upon in the limitations section (Chapter Six). Although these data would have added value to the study, the primary purpose associated with determining muscle activation was not impacted and therefore it was deemed that the study could proceed without the motion capture.

A mono-axial accelerometer (Crossbow CXL10GP1Z \pm 10G, Memsic, California, USA) was secured to the back of the participant's bats as it provides maximal bat speed and accurate timing of bat-ball impact due to the reduction of bat speed following impact. The magnitude of bat speed could not be ascertained as the conversion to $\text{m}\cdot\text{s}^{-1}$ was not accurate and this is a limitation of this study that will be expanded upon in the limitations section (Chapter Six). The accelerometer did aid in determining the timing of impact between the bat and the ball due to a sudden deceleration and was therefore used in testing.

Testing:

This study adapted the method from prior kinematic studies (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021), which used a distance-hitting protocol to determine the effect of lead arm muscle activity on maximal bat speed. The distance-hitting protocol comprised participants hitting straight lofted drives for maximal distance while facing good length deliveries from a bowling machine (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). In the original studies, batters' movements were measured using a motion capture analysis system, however, due to issues determined in the pilot study, this was not included in this study, and the protocol was therefore adapted.

Equipment setup

Testing occurred at the cricket nets of the school that the participants attended at the end of the latter half of the 2022/2023 season (March 2023). Testing comprised of a full-length indoor cricket pitch surrounded by netting to prevent the ball from exiting the nets. The end of the netting had the Brell Express Bowling Machine (Flicx, South Africa) which delivered 12 Brell yellow plastic bowling balls through a hole in the netting to protect the tester from the ball during testing. The testing net had four blue cones placed to ensure a full-length delivery and to control the delivery speed a Radar Speed gun (SR3600, Sports Radar LTD, Homosassa, USA) was used

Anthropometric methods

Stature was recorded using a Harpenden stadiometer, (Holtain Ltd, Crymych, United Kingdom) participants removed their shoes and stood with their heels, back and shoulders against the back of the stadiometer. Mass was measured with a Toledo® electronic scale (Port Melbourne, Australia).

EMG methods

The muscles measured were the triceps brachii, biceps brachii, wrist flexors (located on the lateral humerus epicondyle) and wrist extensors (located on the medial humerus epicondyle) as these muscles result in elbow extension and wrist flexion which have been linked to bat speed generation (Peploe et al., 2018, 2019; McErlain-Naylor et al., 2021). To measure muscle

activity electromyography (Biometrics DataLogger Miniature MWX8) was used whereby surface electrodes were attached to the muscles of interest.

Before attaching the electrodes, the electrode sites were prepared by shaving the hair with disposable razors and wiping the area with isopropyl alcohol and paper towelling (Konrad, 2006). Eight surface electrodes (Skintact FS-TC1 /10, Leonhard Lang GmbH, Austria) were placed parallel to the muscle fibres, two centimetres apart to reduce cross-talk (Konrad, 2006). Muscle location sites were identified and verified by Konrad (2006). In addition to the surface electrodes, a Biometrics goniometer (Ladysmith, USA) and an accelerometer (Crossbow CXL10GP1Z \pm 10G, Memsic, California, USA) were attached to the DataLogger (MXW8).

The Biometrics (Ladysmith, USA) goniometer was placed across the participant's lead elbow joint to measure the magnitude of elbow extension during the different phases of batting. Participants were asked to use an HS cricket bat provided to them (HS Pilano Sports, Pakistan). The mono-axial accelerometer (Crossbow CXL10GP1Z \pm 10G, Memsic, California, USA) was secured to the toe end of the back of the participant's bats to provide maximal bat speed and accurate timing of bat-ball impact due to the reduction of bat speed following impact. The DataLogger (MXW8) was secured to the participant's waist using a belt on the side opposite their lead arm to reduce the chance of the delivery hitting the DataLogger. The DataLogger (MXW8) was recorded at 100 Hz for all inputs with rectification applied in processing for all measurements and Root Mean Square filters applied for muscle activation. Processing of the DataLogger data was performed using the Biometrics DataLog software.

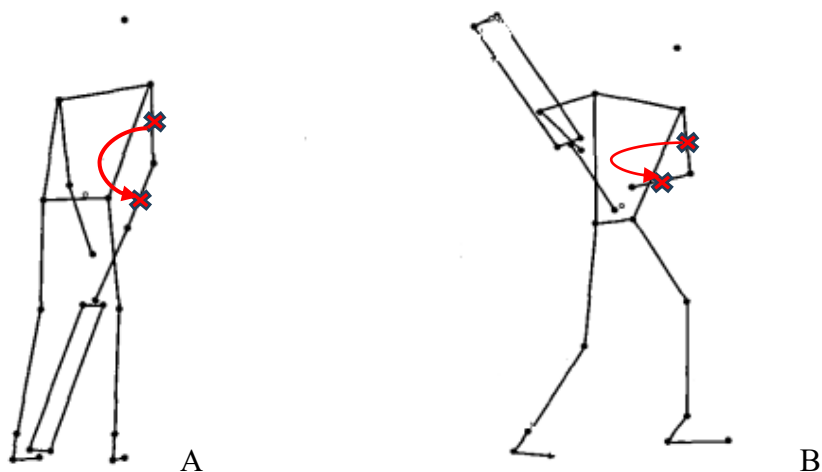


Figure 1: Saggital plain stick figure diagram depicting lead elbow flexion angle decreasing from A to B

Adapted from Stuelcken, Portus and Mason (2005)

Video methods

Mobile phone video from a Samsung Galaxy (A13, South Korea) was also used to distinguish between shot types as well as batter backlift and follow-through techniques. Classification for batter technique using video analyses is an established technique although this study did not use a vector system to increase the accuracy of the classification which is a limitation (Noorbhai and Noakes, 2016). The mobile phone was placed behind protective netting looking down the length of the pitch and the recording was started following warm-up before testing.

Testing

Following placement of the surface electrodes participants were habituated with the equipment by completing a warm-up consisting of facing six deliveries at $80 \text{ km}\cdot\text{h}^{-1}$ as a reduced ball delivery speed to allow the player to perform the desired shot at a reduced difficulty level (Portus et al., 2010). Following setup and warm-up, the participant was ready to commence testing whereby participants faced two to three overs.

The number of overs was dependent on the success of striking the ball to ensure a large enough sample of straight lofted shots whereby each participant had a minimum of three lofted straight shots recorded. Testing ball speed occurred at $100 \text{ km}\cdot\text{h}^{-1}$ which is informed by prior studies (Portus et al., 2010) at a slightly reduced speed to assist players in replicating the desired shot. The ball was delivered from a bowling machine set at a full length aimed at the off-stump for batters.

Participants performed multiple lofted shots straight over the bowler for maximal ball carry distance in the same way as they would have attempted to hit a boundary in a match situation to replicate match conditions for accurate findings.

Data processing methods

In data processing it was decided based on the prior studies that the backlift phase was 0.30 s long, beginning 0.51s before contact and ending 0.21 s before contact, the downswing phase was 0.21 s before contact, contact was 0.01 s and follow through was 0.40 s after contact (Stretch et al., 1998; Stuelcken, Portus and Mason, 2005; Peplow et al., 2018, 2019; McErlain-

Naylor et al., 2021). Contact was established due to the reduction in bat speed, recorded by the accelerometer (Crossbow CXL10GP1Z \pm 10G).

3.6 PROCEDURE

Participants arrived for testing at a time set up by the tester. Participants gave informed assent after re-explaining the testing protocol and then had their demographic information recorded such as their name, age, stature and mass. Participants removed their shoes and any pieces of clothing they would not use when batting like jackets. Demographic information was not used for analysis however was used for comparison to prior kinematic study participants which all had adult participants.

Following this, participants were asked to warm up as they would for batting in a game and were fitted with the equipment. The participant's forearm was shaved, and eight electrodes were placed on the four muscle sites of interest. The DataLogger was secured to the participant by being placed on a belt that the participant fastened around their waist with the DataLogger being placed on the rear hip to limit the chances of it being hit by a ball throughout the test. The goniometer was placed across the participant's elbow joint while the elbow was straight. The electrodes and goniometer were connected to the DataLogger, threading the cables through the participant's shirt by going up the sleeve and out the inside of the waist to prevent pulling of the cables from interfering with the batter technique. The participant was asked to move around and see if any adjustments needed to be made. If no adjustments were needed, then the accelerometer placed at the rear of the toe of the bat was connected to the DataLogger and the testing warm-up was commenced.

The participant faced a warm-up and then the bowling machine speed was adjusted to the testing speed of 100 km·h⁻¹. During warm up the mobile phone video camera was setup behind the protective netting aimed down the length of the pitch. The mobile phone camera started to record and the DataLogger was turned on. The participant faced six deliveries at 100 km·h⁻¹ attempting to hit lofted straight drives. The tester counted down the delivery from three and inserted the ball into the bowling machine following the count of one. If the delivery was not at the desired length or line then it was repeated and data from that delivery was not used for statistical analyses. Following the over the participant would rest for one minute before completing the second over and if necessary due to a lack of completing lofted straight drives

the participant would rest for another minute before completing a third over. Upon completion of the final over testing was complete, the DataLogger was turned off followed by the mobile phone camera and the testing equipment was removed from the participant.

3.7 DATA PROCESSING

Following the recording of muscle activation, lead-elbow angle and accelerometry data, processing was performed using the Biometrics DataLog software. Data was imported to the software and a rectification filter was applied to move all data to the positive Y-axis for ease of comparison. The velocity filter was applied to the accelerometry data to determine changes in velocity for identification of the moment of contact in shots. Lead-elbow angle and muscle activation were then taken for the period stated in 3.5 and submitted for summary data and statistical analyses. To calculate the Muscle Voluntary Contraction percentage (MVC%) the muscle activation voltage at any point in the test was taken as a percentage of the maximum magnitude of voltage measured, for that muscle, in the duration of the test. This was completed for each muscle and the activation percentage was averaged over each phase.

Summary descriptive statistics will be displayed per participant and across all participants (standard deviation, mean, coefficient of variation) for dependent variables. Following this, the shots will be classified into separate types, using mobile phone video footage, to determine if the dependent variables change according to shot type. Shots in the anterior-posterior direction were included, these shots were then separated into shots that were lofted or along the ground and by the direction of the ball post impact. Shots along the ground which impacted the side netting to the leg side before reaching the end of the pitch were classified as leg-flicks (Figure One). Shots which impacted the side netting to the off side before reaching the end of the pitch were classified as cover drives (Figure One). Shots which hit the netting or roof of the netting towards the bowling machine (in front of the batter) without hitting the side netting were classified as straight shots.

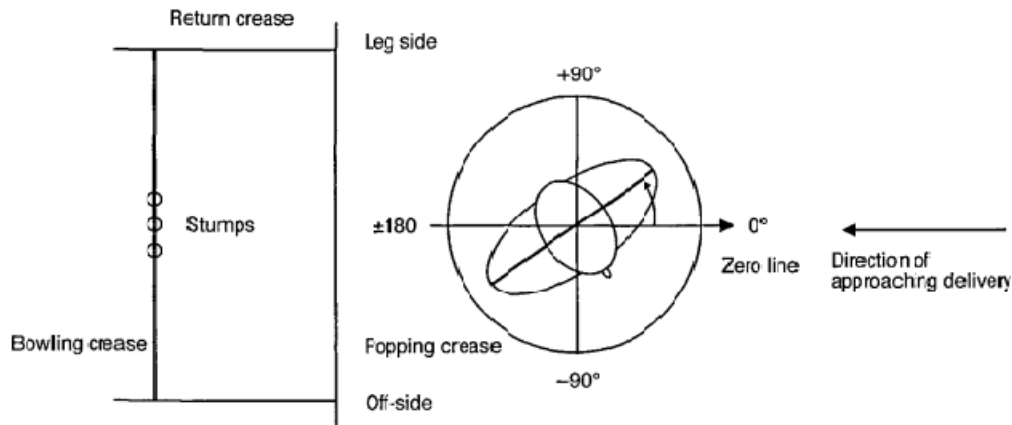


Figure 2: Overhead two-dimensional figure showing classification of leg side and off side for shot classification (Stuelken et al, 2005).

3.8 STATISTICAL ANALYSES

Following data collection, dependent variable data was analysed for normality with a Shapiro-Wilks test. All variables returned a p-value of <0.05 , rejecting the null hypothesis that the data follows a normal distribution. This can be seen in the appendices whereby the distribution is more concentrated to either the low end for the muscle MVC% or the high end for the Lead elbow angle (Appendix 3). Due to the data not having a normal distribution, non-parametric tests were used to establish the variance between dependent variables. To determine the effect of multiple groups on the independent variables a Kruskal-Wallis test for ANOVA was used. Where significant differences were identified, multiple pairwise comparisons were completed to determine where the differences occurred.

CHAPTER 4

RESULTS

Following data collection, two participants had substantial interference with their EMG data and were excluded which reduced the sample to 10 players.

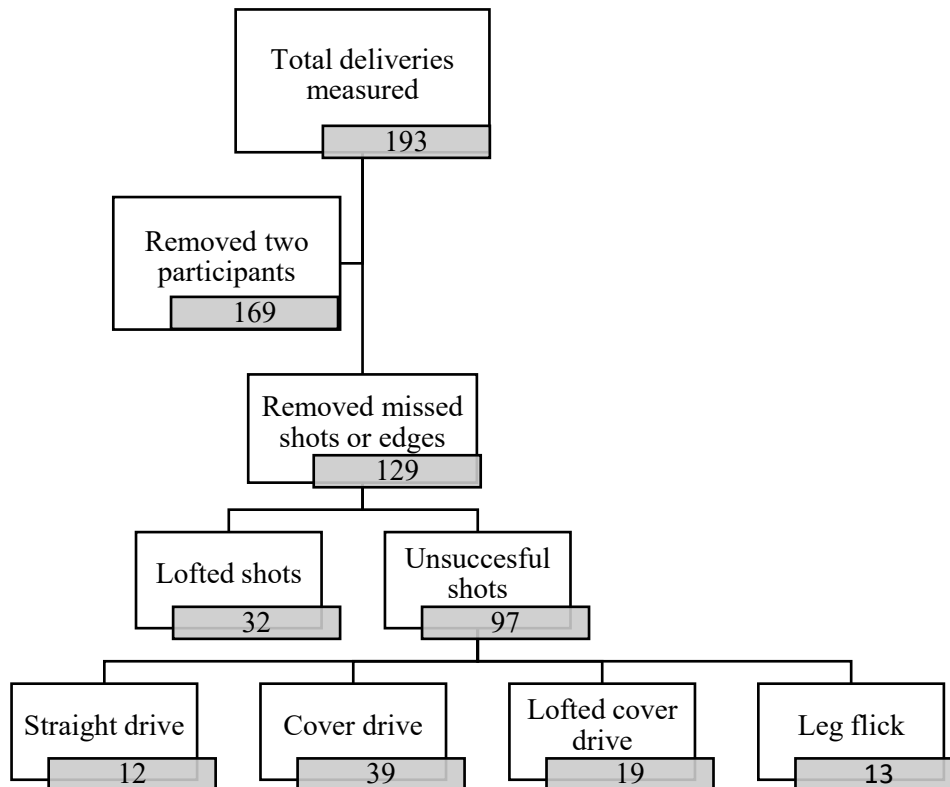


Figure 3: Flow diagram of shot sample selection.

A total of 193 deliveries were measured, following the exclusion of two participants and their 24 samples, the total shots analysed in the study was reduced to 169 shots. From the 169 shots measured 40 were either misses or edges which were excluded as accurate shot timing or predicted shot timing could not be established resulting in 129 shots. Of the 129 shots measured, there were 32 lofted straight shots which were classified as successful shots and all other 97 samples were classified as unsuccessful. Of the 97 unsuccessful shots all shots with a sample for each participant were included as a separate category for the statistical tests. There were four blocks and 10 wide drives which were included as unsuccessful shots however were not included as their column due to the low amount of sample points which resulted in a total shot sample of 115 shots.

Mobile phone video footage was used for the classification of the shot type which was separated into: Straight drive (12 shots), lofted straight drive (32 shots), cover drive (39 shots), lofted cover drive (19 shots) and leg flick (13 shots).

4.1 PARTICIPANT CHARACTERISTICS

Participants had a mean age of 17.5 years (\pm 1.2 years), a mean stature of 176cm (\pm 6.0cm), and a mean mass of 75kg (\pm 14.0kg).

4.2 FINDINGS

Table 6

Statistical p-values from the Kruskal-Wallis test for lead elbow angle and muscle activation

Independent variables	Dependant variables				
	Lead elbow angle	Forearm extensor MVC%	Forearm flexor MVC%	Biceps brachii MVC%	Triceps brachii MVC%
Shot type	p= 0.7879	p= 0.2578	p= 0.4160	p= 0.4043	p= 0.712
Participant	p= 0.000*	p= 0.002*	p= 0.000*	p= 0.000*	p= 0.000*
Phase	p= 0.001*	p= 0.000*	p= 0.000*	p= 0.000*	p= 0.000*

MVC% is the muscle voluntary contraction percentage.
Statistical significance denoted with *

There was no significant difference in lead elbow angle and muscle activation based on shot type, meaning there was not a change in the dependent variables based on the different shots recorded. This may be due to the small sample of shot types observed with five different types of shots. This rejects the alternative hypothesis and tentatively accepts the null hypothesis.

There was a significant difference ($p < 0.05$) in lead elbow angle and muscle activation based on the participants. This rejects the null hypothesis and accepts the alternate hypothesis, meaning that individual participants show different magnitudes in lead elbow angle and MVC% from the other participants.

There was a significant difference ($p < 0.05$) in lead elbow angle and muscle activation based on the different phases of the cricket batting shot. This rejects the null hypothesis and accepts

the alternate hypothesis meaning that the different phases of a cricket batting shot have different demands.

Due to many differences, the results will be discussed in the next section but with the full analyses in the appendices (Appendix Three).

Participants:

Table 7

Number of significant differences for participants in comparison to each other per dependent variable.

Variables	Participants									
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Lead elbow angle	3	3	2	2	3	1	1	9	6	2
Forearm extensor MVC%	1	0	1	1	0	0	0	0	4	1
Forearm flexor MVC%	1	1	1	9	1	1	1	1	1	1
Biceps brachii MVC%	6	5	3	3	2	6	4	3	4	2
Triceps brachii MVC%	0	0	1	0	1	0	0	0	0	0

P1 refers to Participant One, P2 refers to Participant Two, P3 refers to Participant Three, P4 refers to Participant Four, P5 refers to Participant Five, P6 refers to Participant Six, P7 refers to Participant Seven, P8 refers to Participant Eight, P9 refers to Participant Nine, P10 refers to Participant Ten. MVC% is the muscle voluntary contraction percentage. Significant differences are shown in red.

Table 3 displays the number of significant differences per participant, in comparison to the other participants, based on the dependent variables. Multiple comparison z-values following the Kruskal-Wallis Anova allow for the identification of which participants are significantly

different from the rest of the sample for each dependent variable. For each dependent variable, the participant with the greatest number of significant differences in comparison to the other participants is displayed in red text. Participants who were significantly different to other participants executed the shot differently from them.

For the lead elbow angle, all participants had a significant difference ($p < 0.05$) meaning that every participant has a difference in their lead elbow angle to at least one other participant. P8 was significantly different from all the other nine participants by having a lower mean lead elbow angle, showing that they have a unique technique in lead elbow angle when batting. This will be explained in further detail in section 4.4 where significantly different participants are discussed and section 5.2 using tables 15-18. P9 was significantly different from six other participants and the rest of the participants had three or fewer significant differences from the other participants (Table Three).

For the forearm extensor muscle group, Participant Nine was significantly different ($p < 0.05$) from four participants and was the only participant with multiple significant differences for this muscle (Table Three). Participant Nine had a lower mean activation compared to other participants.

For the forearm flexor group Participant Four was significantly different ($p < 0.05$) from all other nine participants and was the only participant with multiple significant differences (Table Three). This shows that they are unique from the other participants, having a lower mean activation compared to other participants.

For the Biceps, all participants have a minimum of two significant differences ($p < 0.05$), indicating they are different from at least two participants. Participant One, Participant Two, and Participant Six have five or greater significant differences representing most of the sample. Therefore, all of the participants show a different muscle activation pattern for the biceps.

For the Tricep participant Three was significantly different ($p < 0.05$) from Participant Five, with Participant Three having greater activation at the contact and follow-through phases.

Batting phase:

Table 8

Mean values of dependent variables for total shots across phases.

Phase	Variable				
	Lead elbow angle	Forearm extensor MVC%	Forearm flexor MVC%	Biceps brachii MVC%	Triceps brachii MVC%
Backswing	157.75° ²	19.22% [*]	11.01% ¹	4.02% ¹	6.15% ¹
Downswing	150.41° ²³	26.00% [*]	26.96%	17.11%	24.33%
Contact	159.83° ^{3"}	48.45% [*]	37.65% ¹	29.96% ¹	44.31% ¹
Follow-through	149.93° ["]	32.52% [*]	25.17%	17.93%	21.02%

Matching symbols show significant relationships between phases.

Variables where backswing was significantly different from contact.

² Variables where backswing was significantly different from downswing.

³ Variables where downswing was significantly different from contact.

^{*} Variables where all batting phases were significantly different from each other.

["] Variables where contact was significantly different from follow-through.

MVC% is the muscle voluntary contraction percentage.

A significant difference indicates that measurements for that phase are different from another phase, showing that they have different demands for each phase. For the lead elbow, the angle decreased from 157.75° during the backswing to 150.41° for the downswing phase before increasing as the elbow was extended to 159.83° at contact and then decreasing as the elbow was flexed into the follow-through phase 149.93°. The backswing was significantly different to the downswing, the downswing was significantly different from contact and the moment of contact was significantly different from follow-through ($p < 0.05$) (Table Four).

For the Forearm extensor, activation increased from 19.22% at backswing to 26.00% during downswing before peaking to 48.45% at contact and then lowering to 35.52% into the follow-through phase. All phases were significantly different from each other ($p < 0.05$) meaning that each batting phase had different levels of muscle activation (Table 4).

For the Forearm flexor, Bicep and Tricep all phases were significantly different from each other ($p < 0.05$) apart from the downswing in comparison to follow-through (Table 4). The demand increases from downswing to contact before reducing into follow-through. For each of these

dependent variables the amount of muscle activation at downswing and follow through are similar indicating similar demands at those phases.

4.3 SHOT TYPE

4.3.1 Backlift

Table 9

Dependent variables for different shots during the backlift phase.

Variable	Shot type					
	Lofted Straight Drive (n=32)	Unsuccessful (n=97)	Cover drive (n=39)	Lofted Cover (n=19)	Leg flick (n=13)	Straight drive (n=12)
Lead	155.25°	157.86°	158.2°	155.47°	157.52°	156.2°
elbow	±2.67	± 2.01	± 1.66	± 2.18	± 11.71	±19.25
angle	[1.72%]	[1.27%]	[1.05%]	[1.40%]	[7.43%]	[12.32%]
Forearm	19.10%	19.34 %	18.18 %	18.42 %	18.05%	14.66%
Extensors	± 3.63	±1.76	±0.69	±2.84	±3.15	±2.53
MVC%	[19.02%]	[9.09%]	[3.81%]	[15.43%]	[17.47%]	[17.24%]
Forearm	8.22%	11.93%	13.49 %	12.85%	11.05%	8.66%
Flexors	±1.71	±2.71	±3.89	±2.58	±3.22	±1.88
MVC%	[20.79%]	[22.70%]	[28.82%]	[20.04%]	[29.15%]	[21.75%]
Bicep	2.61%	4.55%	5.16 %	4.10%	4.05%	1.79%
brachii	±0.83	±1.55	±2.30	±1.19	±1.51	±0.46
MVC%	[31.67%]	[33.98%]	[44.53%]	[29.10%]	[37.25%]	[25.46%]
Tricep	5.13%	6.39%	6.70 %	8.45 %	5.08 %	3.21%
brachii	± 0.81	±1.67	±2.18	±2.62	±2.46	±0.79
MVC%	[15.88%]	[26.13%]	[32.55%]	[31.05%]	[48.37%]	[24.63%]

Number of shot samples represented by n= followed by the number of samples. MVC% is the muscle voluntary contraction percentage.

Note: For each row the top values are the Mean, the middle values are the standard deviation and the third value at the bottom in brackets are the coefficient of variation.

The Batter Elbow angle was very stable across the backlift phase with successful Lofted straight drives having a mean angle of 155.25° compared to Unsuccessful shots (mean angle of 157.86° ± 2.01). The unsuccessful shots' mean angles were within a small range between 155.47° (± 2.18) for Lofted cover shots to 158.2° (± 1.66) for Cover shots and Straight shots having the highest amount of variation at 12.32%.

Forearm Extensors had the greatest mean activation with 19.10% (± 3.63) for Lofted straight drives and 19.34% (± 1.76) for Unsuccessful shots. Muscle activation was similar between Lofted straight drives and Unsuccessful shots with the greatest difference occurring in Forearm flexors with 8.22% (± 1.71) for Lofted straight drives compared to 11.93% (± 2.71) for Unsuccessful shots. Unsuccessful shots had little variation apart from Straight drives which had lower activation across all muscles. The Bicep had the greatest amount of variation due to its low activation (Table Nine).

Table 10

Dependent variable comparison for backlift techniques.

Variable	Shot type				
	Lead elbow angle	Forearm extensor MVC%	Forearm flexor MVC%	Bicep brachii MVC%	Tricep brachii MVC%
SBBT	154.41	29.76%	11.96%	7.24%	12.11%
	±8.84	±9.37	±8.12	±3.25	± 11.48
	[5.73]	[31.49]	[67.87]	[44.97]	[94.79]
LBBT	159.08	16.18%	10.73%	3.09%	4.64%
	±20.59	±7.90	±5.21	±2.91	±3.03
	[12.94]	[48.82]	[27.52]	[35.86]	[41.22]

Number of shot samples represented by n= followed by the number of samples SBBT is straight bat backlift technique, LBBT is lateral bat backlift technique. MVC% is the muscle voluntary contraction percentage.

Note: For each row the top values are the Mean, the middle values are the standard deviation and the third value at the bottom in brackets are the coefficient of variation.

4.3.2 Downswing

Table 11

Dependent variables for different shots during the downswing phase.

Variable	Shot type					
	Lofted Straight Drive (n=32)	Unsuccessful (n=97)	Cover (n=39)	Lofted Cover (n=19)	Leg flick (n=13)	Straight (n=12)
Lead elbow angle	129.52° ± 11.55 [8.92%]	149.24° ± 3.08 [2.06%]	150.72° ± 4.34 [2.88%]	146.66° ± 3.69 [2.52%]	109.53° ± 10.20 [9.32%]	96.3° ± 15.79 [16.38%]
Forearm Extensors MVC%	25.39 % ±10.54 [41.52%]	26.19 % ±10.27 [39.21%]	25.70% ±10.88 [42.34%]	23.36% ±8.32 [35.60%]	28.20% ±15.77 [55.92%]	29.65% ±12.64 [42.62%]
Forearm Flexors MVC%	27.60% ±10.01 [36.26%]	26.74% ±6.45 [24.14 %]	25.79% ±7.24 [28.06%]	29.50 % ±5.65 [19.16%]	28.20% ±5.15 [18.25%]	31.30% ±11.25 [35.94%]
Bicep brachii MVC%	17.12% ±9.79 [57.22%]	17.44% ±5.88 [33.68%]	18.23% ±5.12 [28.09%]	13.76% ±5.41 [39.35%]	20.24% ±8.67 [42.84%]	16.76% ±8.78 [52.42%]
Tricep brachii MVC%	22.43 % ±14.08 [62.77%]	24.09% ±10.71 [44.46%]	25.12 % ±11.11 [44.21%]	24.49% ±9.09 [37.13%]	25.98% ±9.16 [35.25%]	22.73% ±9.60 [42.24%]

Number of shot samples represented by n= followed by the number of samples. MVC% is the muscle voluntary contraction percentage.

Note: For each row the top values are the Mean, the middle values are the standard deviation and the third value at the bottom in brackets are the coefficient of variation.

Lofted straight drives have a more flexed elbow during downswing at $129.52^{\circ} (\pm 11.55)$ compared to $149.24^{\circ} (\pm 3.08)$ for Unsuccessful shots. Within Unsuccessful shots, Leg flick and Straight shots have more flexed elbows at $109.53^{\circ} (\pm 10.20)$ and $96.3^{\circ} (\pm 15.79)$ respectively however there is a low amount of variation (CV= 2.06%). The low number of samples for straight shots and leg flicks will not influence the amount of variation however the differences are important to note.

Forearm Flexors had the greatest mean activation for Lofted straight drives at $27.60\% (\pm 10.01)$ and Unsuccessful shots at $26.74\% (\pm 6.45)$. Lofted straight drives have a higher amount of variation than Unsuccessful shots across all muscles ranging from 36.26% to 63.18% as opposed to 24.14% to 39.60%. Mean activation of forearm muscle groups is greater than upper arm activation in all shots apart from Lofted cover where Tricep activation ($25.37\% \pm 9.94$) is greater than Forearm Extensor activation ($23.36\% \pm 8.32$).

4.3.3 Contact

Table 12

Dependent variables for different shots during the Contact phase.

Variable	Shot type					
	Lofted Straight Drive (n=32)	Unsuccessful (n=97)	Cover (n=39)	Lofted Cover (n=19)	Leg flick (n=13)	Straight (n=12)
Elbow angle	153.44° ± 40.29 [26.26%]	160.13° ± 27.63 [17.26%]	162.27° ± 20.34 [12.53%]	152.14° ± 33.46 [21.99%]	123.50° ± 46.32 [37.50%]	148.64° ± 20.39 [13.71%]
Forearm Extensors	47.48 % ± 16.19	48.98 % ± 19.80	50.18 % ± 22.98	42.35 % ± 17.32	52.62 % ± 20.24	58.23 % ± 16.24

	[34.09%]	[40.42%]	[45.81%]	[40.89%]	[38.46%]	[27.89%]
Forearm Flexors	35.86 % ±16.73 [46.65%]	38.16 % ±18.67 [48.91%]	40.78 % ±19.56 [47.98%]	35.16 % ±18.42 [52.40%]	37.87 % ±17.97 [47.45%]	49.38 % ±20.13 [40.76%]
Bicep	34.61 % ±24.32 [70.28%]	28.41 % ±20.29 [71.42%]	29.58 % ±19.76 [66.82%]	24.44 % ±14.74 [60.31%]	34.57 % ±22.04 [63.73%]	28.43 % ±21.09 [74.21%]
Tricep	51.57 % ±21.45 [41.60 %]	43.92 % ±9.94 [22.63%]	43.82 % ±21.50 [49.06%]	40.18 % ±25.33 [63.04%]	43.99 % ±19.17 [43.58%]	40.89 % ±17.40 [42.56%]

Number of shot samples represented by n= followed by the number of samples. MVC% is the muscle voluntary contraction percentage.

Note: For each row the top values are the Mean, the middle values are the standard deviation and the third value at the bottom in brackets are the coefficient of variation.

Lead elbow angle is more flexed for Lofted straight drives than Unsuccessful shots at 153.44° (± 40.29) compared to 160.13° (± 27.63). Lofted straight drives have a greater variation of Elbow angle with a CV of 26.26% compared to a CV of 17.26% for Unsuccessful shots. Lofted straight-drive muscle activation had a lower amount of variation than Unsuccessful shots with the Bicep having the greatest amount of variation at 70.28% and 71.42% respectively.

The Tricep had the greatest mean activation of 51.07% (± 21.46) for Lofted straight drives and the Forearm Extensor had the greatest mean activation of 48.98% (± 19.80) for Unsuccessful shots. The difference in activation for Unsuccessful shots may be due to greater Forearm Extensor activation for the Cover, Leg flick and Straight shot at 50.18% (± 22.98), 52.62% (± 20.24) and 58.23% (± 20.39) respectively. Unsuccessful shots along the ground had greater Forearm Flexor activation with 40.78% (± 19.56) for the Cover drive and 49.38% (± 20.13) for the Straight drive.

4.3.4 Follow-through

Table 13

Dependent variables for different shots during the follow-through phase.

Variable	Shot type					
	Lofted Straight Drive (n=32)	Unsuccessful (n=97)	Cover (n=39)	Lofted Cover (n=19)	Leg flick (n=13)	Straight (n=12)
Elbow angle	144.87° ± 12.86 [8.88%]	149.59° ± 5.72 [3.82%]	149.85° ± 6.01 [4.01%]	141.59° ± 7.74 [5.47%]	138.69° ± 18.27 [13.17%]	147.20° ± 13.41 [9.11%]
Forearm Extensors	37.13% ±13.43 [36.16%]	31.28% ±12.07 [38.57%]	29.98% ±13.66 [45.56%]	27.35% ±9.76 [35.67%]	29.10% ±10.78 [37.04%]	38.97% ±15.29 [39.23%]
Forearm Flexors	25.41% ±10.50 [41.34%]	25.20% ±8.81 [34.97%]	26.02% ±8.47 [32.54%]	23.68% ±6.80 [28.71%]	25.18% ±10.66 [42.33%]	31.78 % ±10.74 [33.81%]
Bicep	19.95% ±12.08 [60.55%]	17.57% ±6.77 [38.52%]	21.50 % ±5.54 [25.77%]	14.68% ±8.86 [60.36%]	12.88% ±8.90 [69.10%]	14.08% ±5.63 [39.97%]
Tricep	22.59% ±13.85 [61.31 %]	21.13% ±10.46 [49.53%]	21.74 % ±9.35 [42.99%]	18.60% ±8.94 [48.08%]	17.66% ±12.93 [73.23%]	23.57 % ±9.60 [40.74%]

Number of shot samples represented by n= followed by the number of samples. MVC% is the muscle voluntary contraction percentage.

Note: For each row the top values are the Mean, the middle values are the standard deviation and the third value at the bottom in brackets are the coefficient of variation.

The lead means the Elbow angle was more flexed for Lofted straight drives at $144.87^\circ (\pm 12.86)$ than Unsuccessful shots at $149.59^\circ (\pm 5.72)$. Lofted straight drives had greater variability for lead Elbow angle (CV=8.88%), Forearm flexor activation (CV=41.34%), Bicep activation (60.55%) and Tricep activation (60.80%).

Forearm Extensors had the greatest mean activation for both Lofted straight drives ($37.13\% \pm 13.43$) and Unsuccessful shots ($31.28\% \pm 12.07$). The Cover drive had greater Bicep activation ($21.50\% \pm 5.54$), the Straight drive had greater Forearm Extensor activation ($38.97\% \pm 15.29$), Forearm Flexor activation ($31.78\% \pm 10.74$) and Tricep activation ($24.43\% \pm 10.41$).

Table 14

Comparison of follow-through dependent variables.

Variable	Backlift technique	
	Checked	Full
Lead-elbow angle	140.73° ±13.38 [9.50%]	152.09° ±7.65 [5.03%]
Forearm Extensor MVC%	34.75% ±12.01 [34.57%]	28.05% ±12.29 [43.80%]
Forearm Flexor MVC%	26.64% ±10.79 [40.48%]	21.69% ±7.982 [36.80%]
Bicep brachii MVC%	17.94% ±10.68 [59.56%]	19.70% ±5.89 [29.87%]
Tricep brachii MVC%	20.65% ±10.16 [49.20%]	22.33% ±11.55 [51.71%]

Number of shot samples represented by n= followed by the number of samples. MVC% is the muscle voluntary contraction percentage.

Note: For each row the top values are the Mean, the middle values are the standard deviation and the third value at the bottom in brackets are the coefficient of variation.

The checked follow-through has a more flexed elbow (140.73°) with greater activation in the forearm extensor (34.75%) and forearm flexor (26.64%) muscle groups as compared to the full

follow-through. The full follow-through had a greater amount of activation in the bicep (19.70%) and the tricep (22.33%) muscle groups.

4.4 UNIQUE PARTICIPANTS:

Significantly different participants have unique muscle activation or lead elbow patterns indicating that there are differences in their technique as compared to the other players in the squad. These differences will be explained by analysing the technique through stills taken from video footage and discussing the muscle activation or lead elbow patterns to determine why these differences may occur.

Figures Two, Four and Six show the mean measurements of all participants over their successful shot samples to provide greater detail than Tables 15-18 as the activation changes within each phase. For this paper, the unique participants are analysed in further detail below however the variation of each participant in the sample over the shot shown by figures Two, Four and Six can allow for a greater understanding of each participant. This greater understanding was detailed in individual reports for each participant in Appendix Two as it was not one of the aims and objectives of this paper.

4.4.1 Participant four

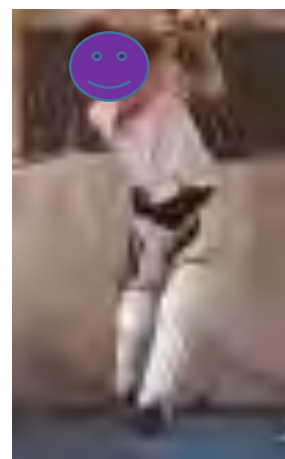
Participant Four shows unique Forearm flexor MVC% from all other participants.



P4: backswing



P4: contact



P4: Follow through

Figure 4: Participant Four (P4) during batting phases.

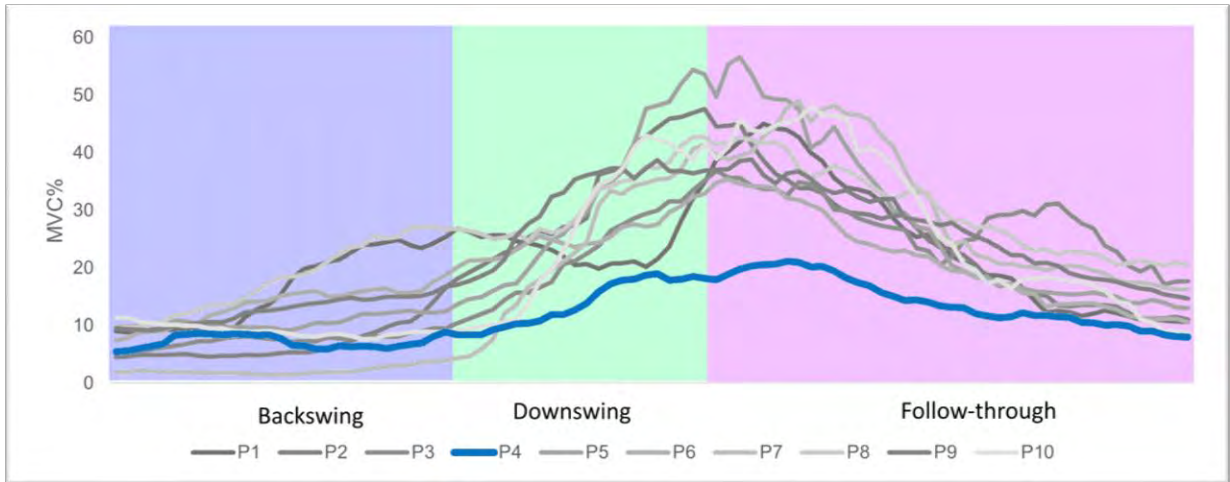


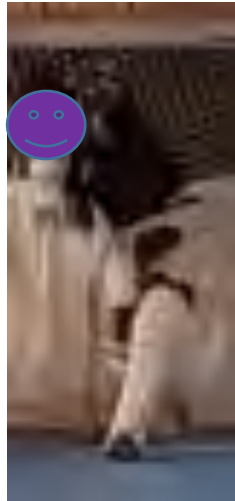
Figure 5: Forearm flexor MVC% for participants over batting phases.

P1 refers to Participant One, P2 refers to Participant Two, P3 refers to Participant Three, P4 refers to Participant Four, P5 refers to Participant Five, P6 refers to Participant Six, P7 refers to Participant Seven, P8 refers to Participant Eight, P9 refers to Participant Nine, P10 refers to Participant Ten. MVC% is the muscle voluntary contraction percentage.

Participant Four, represented by the blue line in Figure two is of note due to the difference ($p < 0.05$) from the other participants. The mean MVC% represented by the lines in Figure two shows the change in activation occurring across the different phases of the shot. Participant Four has a lower amount of mean activation in the forearm flexor particularly in the downswing phase, at contact and into the follow-through phase.

4.4.2 Participant eight

Participant Eight shows a unique Lead elbow angle from all other participants



P8: backswing

P8: contact

P8: Follow through

Figure 6: Participant Eight (P8) during batting phases.

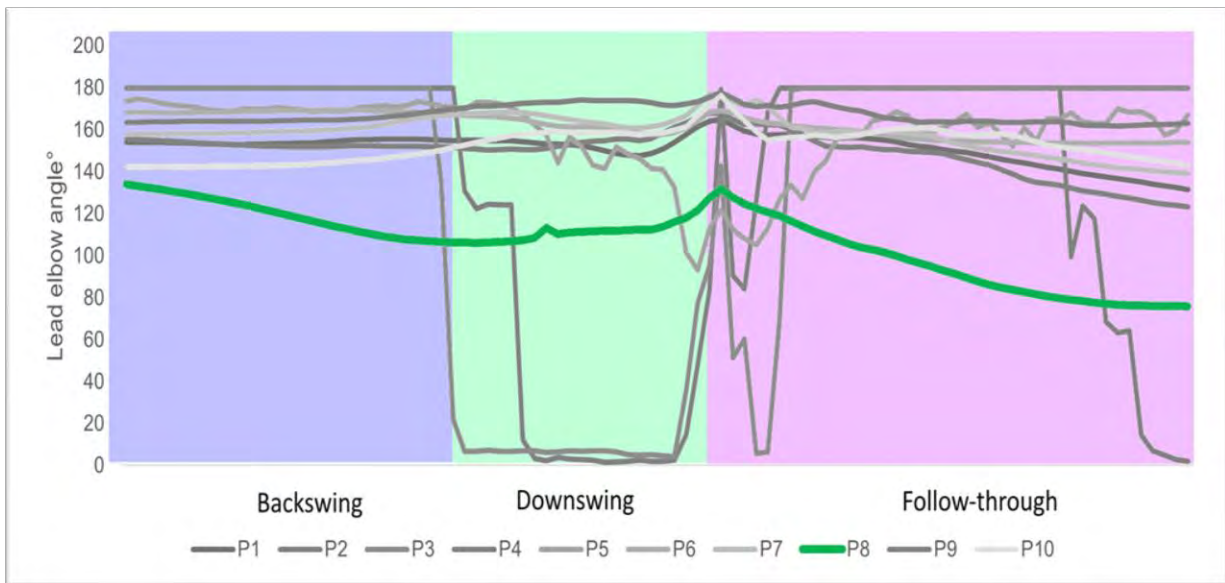


Figure 7: Lead elbow angle for participants over batting phases.

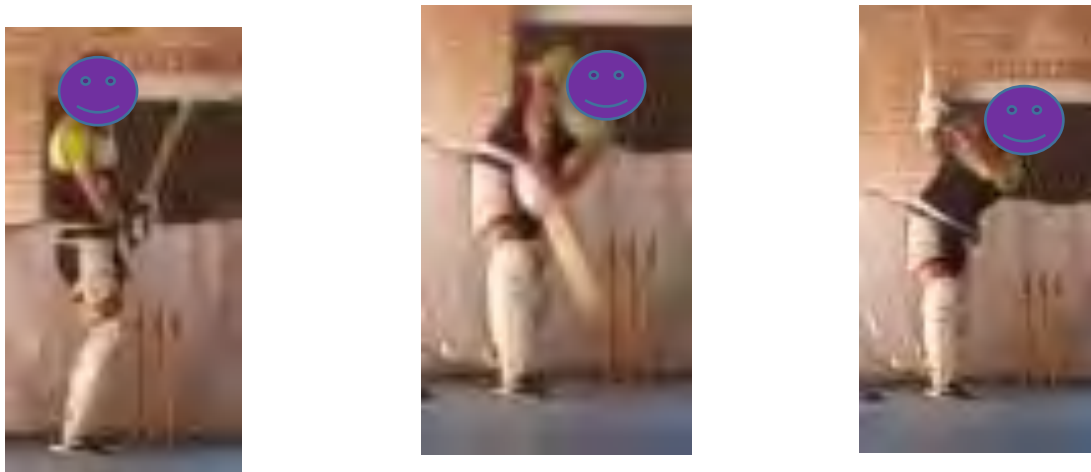
P1 refers to Participant One, P2 refers to Participant Two, P3 refers to Participant Three, P4 refers to Participant Four, P5 refers to Participant Five, P6 refers to Participant Six, P7 refers to Participant Seven, P8 refers to Participant Eight, P9 refers to Participant Nine, P10 refers to Participant Ten. MVC% is the muscle voluntary contraction percentage.

Participant Eight, represented by the green line in Figure four, was different ($p < 0.05$) from all other participants. The mean lead elbow angle for participants across the shot is shown above whereby a lesser lead elbow angle occurs when the participant bends the arm such as in the

downswing phase. Participant Eight has a lower mean lead elbow angle in comparison to the other participants.

4.4.3 Participant Nine

Participant Nine shows unique Forearm extensor MVC% from all other participants.



P9: backswing

P9: contact

P9: Follow through

Figure 8: Participant Nine (P9) during batting phases.

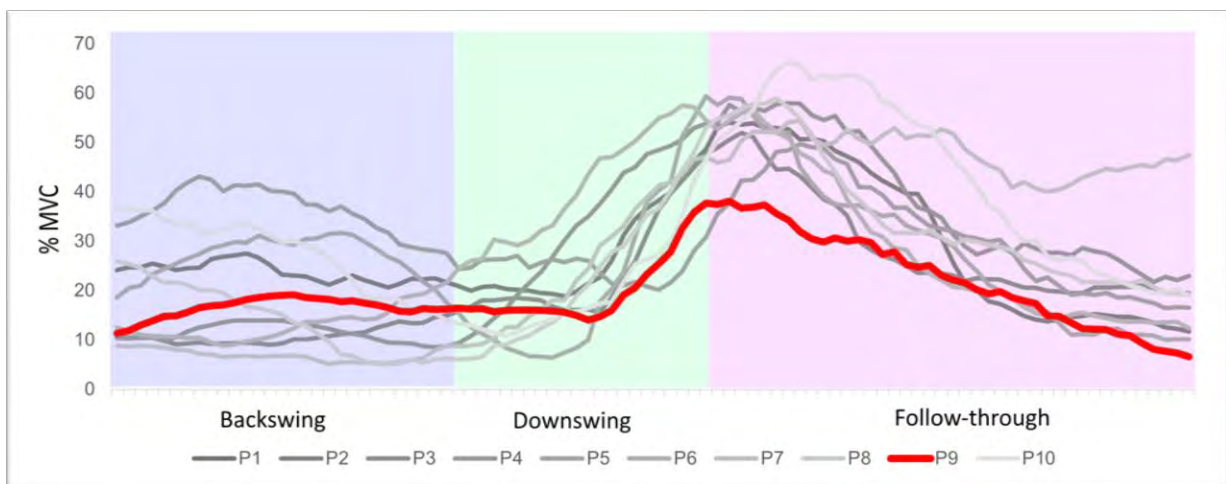


Figure 9: Forearm extensor MVC% for participants over batting phases.

P1 refers to Participant One, P2 refers to Participant Two, P3 refers to Participant Three, P4 refers to Participant Four, P5 refers to Participant Five, P6 refers to Participant Six, P7 refers to Participant Seven, P8 refers to

Participant Eight, P9 refers to Participant Nine, P10 refers to Participant Ten. MVC% is the muscle voluntary contraction percentage.

Participant Nine, represented by the red line in Figure six was different ($p < 0.05$) to all other participants and is the only left-handed batter in the study. The mean MVC% represented by the lines in Figure six shows the change in activation occurring across the different phases of the shot. Participant Nine has a lower mean activation compared to the other participants, particularly in the follow-through phase.

4.5 INTER-PARTICIPANT RESULTS

The following tables show the mean MVC% and lead elbow angles for all participants across the different phases of their successful shot samples. In conjunction with figures two, four and six they show where the significantly different participants differ from the rest of the sample. Figures Two, Four and Six in addition to the following tables (15-18) are used to create the individual reports in Appendix Two and allow for a greater understanding of each participant.

Table 15

Participant mean and standard deviation measurements during the backswing phase of batting.

Variable	Participants									
	P1 *	P2	P3	P4 *	P5	P6	P7	P8	P9	P10
Elbow angle	154.32° ±0.90	178.37° ±8.94	167.45° ±42.45	152.86° ±1.22	170.89° ±1.67	168.65° ±0.66	160.78° ±3.13	118.92° ±9.54	165.40° ±1.97	144.88° ±3.04
Forearm Extensor	23.65% ±2.01	11.05% ±1.98	11.39% ±1.84	35.88% ±5.17	26.34% ±4.64	13.59% ±4.07	6.94% ±1.26	13.91% ±7.25	16.52% ±2.02	27.09% ±7.86
Forearm Flexor	16.71% ±6.77	7.27% ±3.76	7.59% ±1.22	7.21% ±1.12	10.78% ±1.21	13.78% ±3.34	2.29% ±0.80	18.49% ±6.31	12.77% ±2.44	9.15% ±0.97
Bicep	8.17% ±4.10	3.34% ±1.92	1.15% ±0.31	6.30% ±0.73	2.04% ±0.97	9.95% ±1.48	0.44% ±0.22	3.54% ±2.67	3.94% ±1.29	2.24% ±0.75

Tricep	5.48% ±3.18	1.56% ±1.26	1.87% ±0.65	17.25% ±3.88	4.13% ±1.00	7.84% ±2.66	1.02% ±0.92	4.26% ±2.23	5.56% ±2.92	6.92% ±1.18
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* Indicates that the participant used a Straight Bat Backlift Technique (SBBT). P1 refers to Participant One, P2 refers to Participant Two, P3 refers to Participant Three, P4 refers to Participant Four, P5 refers to Participant Five, P6 refers to Participant Six, P7 refers to Participant Seven, P8 refers to Participant Eight, P9 refers to Participant Nine, P10 refers to Participant Ten.

Table 16

Participant mean and standard deviation measurements during the downswing phase of batting

Variable	Participants									
	P1 *	P2	P3	P4 *	P5	P6	P7	P8	P9	P10
Elbow angle	153.48° ±4.11	32.76° ±49.38	15.38° ±24.77	155.38° ±5.22	146.90° ±22.22	162.43° ±3.15	165.87° ±3.90	112.32° ±5.28	172.99° ±1.14	159.20° ±3.79
Forearm Extensor	27.99% ±10.18	24.56% ±10.90	33.95% ±14.48	24.68% ±2.75	22.59% ±17.95	41.98% ±11.32	26.47% ±13.35	24.02% ±14.63	20.28% ±7.34	20.82% ±10.44
Forearm Flexor	24.07% ±3.93	33.04% ±10.03	22.77% ±7.69	14.16% ±3.95	32.48% ±14.01	25.76% ±3.45	24.90% ±11.78	31.94% ±6.32	31.73% ±7.07	27.60% ±13.03
Bicep	25.95% ±2.69	29.27% ±17.01	11.88% ±8.75	9.51% ±1.86	14.46% ±6.42	23.48% ±7.92	7.99% ±6.11	17.51% ±7.23	13.81% ±5.34	21.25% ±12.72
Tricep	27.63% ±12.49	21.76% ±15.20	13.50% ±7.31	27.56% ±9.77	15.86% ±8.47	23.83% ±10.21	16.23% ±16.61	25.42% ±8.38	29.06% ±7.82	20.78% ±13.21

* Indicates that the participant used a Straight Bat Backlift Technique (SBBT). P1 refers to Participant One, P2 refers to Participant Two, P3 refers to Participant Three, P4 refers to Participant Four, P5 refers to Participant Five, P6 refers to Participant Six, P7 refers to Participant Seven, P8 refers to Participant Eight, P9 refers to Participant Nine, P10 refers to Participant Ten.

Table 17*Participant mean and standard deviation measurements during the contact phase of batting.*

Variable	Participants									
	P1 *	P2	P3	P4 *	P5	P6	P7	P8	P9	P10
Elbow angle	164.89° ±11.27	179.40° ±52.54	143.00° ±64.09	168.12° ±19.41	121.97° ±32.86	169.17° ±9.70	176.86° ±2.85	131.86° ±21.57	177.88° ±2.06	176.37° ±5.79
Forearm Extensor	53.06% ±17.22	48.98% ±14.36	53.98% ±17.90	35.49% ±17.32	57.56% ±27.99	52.68% ±18.85	45.84% ±12.15	54.84% ±17.07	37.44% ±22.98	50.52% ±17.92
Forearm Flexor	38.82% ±17.72	44.53% ±20.23	36.82% ±15.95	17.95% ±7.59	49.74% ±30.51	34.85% ±12.59	39.57% ±10.43	41.37% ±15.61	37.06% ±14.32	38.95% ±20.15
Bicep	24.86% ±7.63	50.87% ±17.33	27.77% ±21.45	17.26% ±14.31	23.00% ±10.54	44.09% ±24.43	28.19% ±21.75	30.32% ±26.02	24.98% ±13.27	41.49% ±19.60
Tricep	50.14% ±18.69	56.44% ±15.36	27.94% ±17.19	46.44% ±27.89	19.56% ±19.56	44.63% ±16.88	55.59% ±22.99	34.70% ±16.77	37.92% ±22.11	41.92% ±20.84

* Indicates that the participant used a Straight Bat Backlift Technique (SBBT). P1 refers to Participant One, P2 refers to Participant Two, P3 refers to Participant Three, P4 refers to Participant Four, P5 refers to Participant Five, P6 refers to Participant Six, P7 refers to Participant Seven, P8 refers to Participant Eight, P9 refers to Participant Nine, P10 refers to Participant Ten.

Table 18

Participant mean and standard deviation measurements during the follow-through phase of batting.

Variables	Participants									
	P1 *	P2	P3	P4 *	P5	P6	P7	P8	P9	P10
Elbow angle	147.91° ± 9.03 [0.58%]	138.47° ±63.05	162.34° ±48.25	143.69° ±12.75	153.91° ±18.22	156.94° ±4.03	153.39° ±9.86	94.22° ±16.41	165.98° ±4.00	155.15° ±5.85
Forearm Extensor	30.36% ±16.52 [8.51%]	28.21% ±10.61	37.96% ±13.36	31.73% ±11.33	28.12% ±15.64	27.61% ±15.00	47.74% ±4.24	33.88% ±13.09	22.07% ±9.66	42.96% ±17.22
Forearm Flexor	24.49% ±12.16 [40.49%]	23.46% ±10.29	27.41% ±5.34	14.19% ±4.27	27.71% ±14.46	20.90% ±8.04	30.28% ±12.12	29.77% ±7.57	26.38% ±7.70	27.75% ±13.71
Bicep	30.07% ±3.87 [50.22%]	19.49% ±13.66	17.94% ±4.28	15.35% ±10.23	13.41% ±6.38	26.21% ±9.71	14.46% ±9.84	11.83% ±9.14	13.68% ±6.61	22.23% ±17.11
Tricep	20.70% ±11.56 [8.51%]	22.33% ±15.44	22.05% ±6.20	18.58% ±11.63	13.62% ±3.60	25.17% ±8.58	22.70% ±14.64	17.80% ±8.12	18.05% ±7.91	22.31% ±13.04

* Indicates that the participant used a Straight Bat Backlift Technique (SBBT). P1 refers to Participant One, P2 refers to Participant Two, P3 refers to Participant Three, P4 refers to Participant Four, P5 refers to Participant Five, P6 refers to Participant Six, P7 refers to Participant Seven, P8 refers to Participant Eight, P9 refers to Participant Nine, P10 refers to Participant Ten.

Participant One and Participant Four used a Straight Bat Backlift Technique (SBBT) as opposed to the rest of the participants, who used a Lateral Bat Backlift Technique (LBBT). SBBT participants recorded similar Elbow angles (154.32° for Participant One ± 0.90 and 152.86° ± 1.22 for Participant Four), greater mean Tricep activation than other participants (23.65% ± 2.01 for Participant One and 17.25% ± 3.88 for Participant Four) and the Forearm Extensor had the greatest or equal to the greatest activation (23.65% ±2.01 for Participant One and 35.88% ± 5.17 for Participant Four).

LBBT participants had less flexed elbow angles except for Participant Eight ($118.92^{\circ} \pm 9.54$) and Participant Ten ($144.88^{\circ} \pm 3.04$). The Forearm Extensor had the greatest mean activation for all participants apart from Participant One (equal Tricep activation), Participant Six (Forearm Flexor = $13.78\% \pm 3.34$) and Participant Eight (Forearm Flexor = $18.49\% \pm 6.31$). The lead Elbow angle had a low amount of variation apart from Participant Three (CV=25.35%) indicating a stable position at backlift.

4.6 SUMMARY OF RESULTS

Shot type was the only independent variable that did not have an effect on batter muscle activation or lead elbow angle (Table Six). This may be due to the testing procedure requiring batters to approach every ball with the intent to hit a straight lofted drive and will be discussed further in 5.1.2. All dependent variables were significantly different for participant and batting phase rejecting the null hypotheses to show that individuals differ from one another and differ based on the phase of the shot (Table Eight).

The individual differences in participant lead elbow angle and muscle activation indicate certain participants as having unique batting activation patterns which may be due to unique techniques, compared to the rest of the sample (Table Seven). The difference between lead elbow angle and muscle activation for batting phases indicates a change in the demands of batters for each phase (Table 10). These differences may indicate a need to prepare batters for each phase of a shot depending on the demands of the phase and the need for certain individuals to be prepared according to their technique.

CHAPTER 5

DISCUSSION

Differences were found for batting phases which show different demands at each phase. Differences were also found for participants, with individuals having their own techniques and unique ways of approaching the delivery. Shot type was not found to have a significant difference in muscle activation and lead arm elbow angle however this is likely due to the participants aiming to hit a lofted straight drive for each shot and then adapting as the delivery is made. Although there was not a significant difference due to this approach, patterns of activation were apparent.

5.1 INTER-PARTICIPANT

5.1.1 Successful shots compared to unsuccessful shots across batting phases.

Backlift

The backlift phase of batting had the lowest amount of variation for measured variables with a coefficient of variation of 1.72% for elbow angle and between 8.79% – 31.67% for MVC%.

The low variation of elbow flexion indicates a stable starting position across all batters before ‘ball release’ from the bowling machine. Successful Lofted straight drives had a slightly more flexed lead elbow angle than unsuccessful shots however it is unclear if this is significantly linked to the outcome.

Two of the participants had a straight bat backlift technique and the other eight participants had a lateral bat backlift technique; a preferred technique which has been shown by others (Stuelken, Portus and Mason, 2005; Taliep, Galal and Vaughn, 2007). The SBBT had a more flexed elbow and a greater mean MVC% for the forearm flexor muscles and triceps brachii. The higher elbow flexion may be to allow extra space for bat speed generation as an LBBT allows for the greater space whereas an SBBT may need to compensate. The SBBT requires lifting the bat with the lead hand, resulting in greater Forearm extensor activation however the reason for the increased triceps brachii activation is unclear. Due to the small sample size, the backlift phase will be discussed more generally with recommendations for future research on the muscle activation differences in technique.

During the backlift phase, the Forearm extensor had the highest amount of muscle activation (19.10%), which may be due to batters raising the bat in preparation for ball delivery. Due to having the highest amount of activation the Forearm Extensor may need greater muscular endurance to withstand the demands of repetitively ‘cocking’ the wrist in preparation for ball delivery. The desired shot in the test was the lofted straight drive so the result of a higher mean activation of the forearm extensors may only apply to a lofted straight drive, thus more research is needed to determine if this applies to all shots.

Unsuccessful shots had higher mean MVC% across all muscles however it is unclear whether this is linked to shot outcome. Potential explanations for increased activation may be due to the anticipation effect. This may affect MVC% whereupon participants increase activation before ball release to prepare for the task or participant MVC% increases in anticipation of future demands rather than current demands. Muscle activation of the Forearm flexor (8.22%), Bicep (2.61%) and Tricep (5.99%) are low during this phase. The Bicep brachii is an elbow flexor under contraction and thus is the main mover of the elbow into flexion measured in this task. The low MVC% of the bicep in this phase indicates it is not under demand during this phase.

Downswing

Elbow angle decreased as batters flexed their elbow in preparation for the chosen shot, successful shots had a higher flexion angle than unsuccessful shots. It is unclear if the change in elbow flexion is due to adapting to the incoming delivery and executing another shot based on the demands of that delivery which may not have suited a Lofted straight drive. The coefficient of variation for elbow angle in unsuccessful shots was low at 2.06% compared to 8.92% for successful shots and with a high sample of 101 deliveries, it would indicate a stable pattern across batters for elbow orientation in the downswing.

In prior studies, elite male batters had a more flexed lead elbow angle of 121.2° with a CV of 8.91% whereas elite female cricketers had a less flexed lead elbow angle of 133.7° with a CV of 20.57% (McErlain-Naylor et al., 2016, 2021). In comparison to prior studies, the participants of this study have a slightly less flexed lead elbow with a similar amount of variation to elite male batters but display different kinematic patterns to elite female batters with a lesser amount of movement variation.

Variation increased into the downswing phase for MVC% (CV= 36.26% - 63.18%), as the batters adjust to the incoming ball and orientate themselves. The variation may indicate the

need to adapt to every delivery or the lack of a set number of demands for the desired shot. Forearm extensors increase from a mean activation of 19.10% to a mean activation of 25.39%, this increase of 6.29% is less than that of the other muscles. Forearm flexors increase by 19.38% to a mean of 27.60% in the downswing phase. The Bicep increases by 14.51% to a mean of 17.12% and the Tricep increases by 19.22% to a mean of 25.21% for the downswing phase. The increase in activation occurs in the final 0.30s before contact and shows a rapid increase due to the fast nature of a cricket shot.

The increase in the bicep activation may be due to the flexion at the elbow which may result in the tricep increasing due to antagonistic muscle lengthening. The forearm flexor likely increases in activation due to the 'wrist uncocking' known to contribute to bat speed generation (McErlain-Naylor et al., 2021). Another explanation for muscle activation increasing may be due to anticipation. Unsuccessful shots had similar mean MVC% per muscle to successful shots with less variation, possibly due to a greater number of sampling points. The increase in muscle activation during downswing may therefore be due to a general pattern for cricket batting.

Contact

Elbow angle increased as batters extended their elbows into contact with the ball with a mean angle of 153.44° for successful shots and 160.13° for unsuccessful shots. There was a higher amount of variation with a CV of 26.26% for successful shot elbow angle and 17.26% for unsuccessful shot elbow angle. The lower amount of variation for unsuccessful shots may be due to a greater number of sampling points while the greater variation seen in this phase may be due to batters adapting to each shot should there be ball deviation off the pitch.

The mean lead elbow angle at contact is comparable to prior studies finding that elite male cricketers had a mean lead elbow angle of 150.9° with a CV of 9.08% (McErlain-Naylor et al., 2021). Elite female batters had a more flexed lead elbow angle of 130.8° with a CV of 20.72% indicating that different batting techniques are present between sexes from adolescence (McErlain-Naylor et al., 2021).

Muscle activation increased with the Tricep having the highest mean activation at 51.07% for successful shots and the Forearm extensor having the highest mean activation at 48.98% for unsuccessful shots. Variation increased with a CV of between 34.09% - 70.28% for successful shots and had less variation for each muscle than for unsuccessful shots 40.42% - 71.42%. Whereas the greater number of samples for unsuccessful shots had less variation for other

measures such as the lead elbow angle, this is the only instance of it having a greater amount of variation. This may be due to the short period of this batting phase which provides more of a snapshot of muscle activity rather than an average being for 0.01s. It may also be partly due to the need for prospective neuromuscular control whereby batters adjust to the delivery rather than predictive neuromuscular control whereby they move towards the ball based on patterns of movement learned over time for batting (Goble and Christie, 2016).

In successful shots Forearm extensor MVC% increased by 22.09% for a mean of 47.48% at contact, Forearm flexors increased by 8.26% for a mean of 35.86% at contact, Bicep activation increased by 17.49% to a mean of 34.61% at contact and increased by 25.86% to a mean of 51.07% at contact. The Forearm extensor, Bicep and Tricep increased significantly with the Bicep and Tricep doubling in activation. The Tricep is the main elbow extensor and may be linked to the extension of the lead elbow which was identified by prior studies as important for bat speed generation. Bicep activation may be due to antagonistic lengthening while the elbow extends or due to bracing for impact with the ball. Forearm extensor activation may be due to the top hand resisting the bat as the lower arm pushes the bat handle into the top hand which needs to maintain control.

Unsuccessful shots had a similar amount of activation for the Forearm extensor and Forearm flexor however less activation for the Bicep and Tricep. This may show the unique needs for the Lofted straight drive as compared to other shots as the amount of elbow flexion and extension may relate to muscle activation.

Follow-through

The elbow flexed from the contact phase to 144.87° with a decreased variation of 8.88% for successful shots and 149.59° with a decreased variation of 3.82% for unsuccessful shots. The decreased variation shows a slight trend of batters reaching a ‘constant’ endpoint when completing a shot. In cricket, the follow-through can be categorized as either a checked follow-through where batters raise the bat following impact but do not place the bat over or behind the lead shoulder and a full follow through where batters continue with the bat until it passes behind or over the lead shoulder (Stuelcken, Portus and Mason, 2005). For this study, four participants had a full follow-through and six had a checked follow-through. Checked follow-throughs had a more flexed elbow and a higher mean MVC% for the forearm extensor as shown in Table 14. The more flexed elbow is due to not placing the bat over the shoulder and the higher mean

MVC% of the forearm extensor may be due to the top hand resisting the bat being pushed into it by the bottom hand in the figure nine position.

Muscle activation variation has decreased from the contact phase however is still high at between 36.16% - 60.80% for successful shots. This may be due to the lower number of sample points as variation is lower for unsuccessful shots which is between 17.57% - 31.28%. The Forearm extensor is the only muscle with less variation for successful shots (36.16%) than in unsuccessful shots (38.57%). Mean MVC% is similar for successful shots and unsuccessful shots showing a similar number of demands despite different shot outcomes. The Forearm extensor has the highest amount of mean MVC% at 37.13% for successful shots and 31.28% for unsuccessful shots, indicating it is the muscle with the greatest demand in this phase.

The lower variation with higher mean MVC% for successful shots indicates that lofted straight drives potentially have a higher demand than unsuccessful shots. This is due to the greater mean bat speed during the downswing phase for the lofted straight drive between $22.6 \text{ m}\cdot\text{s}^{-1}$ - $28.4 \text{ m}\cdot\text{s}^{-1}$ (Peploe et al., 2018; McErlain-Naylor et al., 2021) in comparison to other shots with mean bat speeds between $10.7 \text{ m}\cdot\text{s}^{-1}$ - $16 \text{ m}\cdot\text{s}^{-1}$ (Elliott et al., 1993; Stretch et al., 1998; Stuelcken, Portus and Mason, 2005; Taliep, Galal and Vaughn, 2007).

Mean MVC% is similar for the other muscles in successful and unsuccessful shots and thus does not indicate different demands based on the shot outcome.

5.1.2 Unsuccessful shots are divided into further categories across batting phases.

Looking further into the unsuccessful shots most samples (58 of 83 shots) can be sub-divided into a cover and lofted cover shot. The higher elbow angle of unsuccessful shots is thus largely influenced by the cover and lofted cover shots however the variation when further dividing the samples shows unique elbow angles based on each shot.

The difference between these shots is whether the batter achieved elevation on the shot or if it was hit along the ground, this difference can be seen in the lead elbow angle. Other unsuccessful shots with sufficient samples to be subdivided into their classification are the leg flick, consisting of 13 shots and the straight drive consisting of 12 shots. Straight drives are lofted straight drives without elevation that were hit along the ground and can thus be compared to them. Leg flicks consist of shots hit towards the leg side for cricket batters, this is largely due to the line being more towards the batter's legs than away from them on the off-stump. It

is classed as a flick as most deliveries were full and were ‘flicked’ off of their toes in a direction square or perpendicular to the batter rather than driven down the pitch towards the bowling machine.

Backlift

During the backlift phase, the mean elbow angle was similar for all classifications between 156.20° - 158.20° with a small amount of variation. The leg flick and straight drive had greater variation at 7.43% and 12.32% respectively however this may be due to the smaller number of sample points. The low variation and similar elbow angle show a stable starting position for the backlift phase. Lead elbow angle in the backlift phase in this study is comparable to the stance, backlift and stride phase for Stretch et al (1998) where a mean front elbow angle of 137°, 144° and 127° were shown respectively. The backlift phase is also comparable to the backlift phase by Elliott et al (1988) with a front elbow angle of 121° and Stuelken, Portus and Mason (2005) with a lead elbow angle of 109°. Prior studies recorded a more flexed lead elbow angle, this may be due to the level of representation of participants with prior studies using professional cricketers.

For all shots, the Forearm extensor had the highest mean MVC% between 14.66% - 18.42%, followed by the Forearm flexor between 8.66% - 13.49%, Tricep between 4.09% - 9.72% and the Bicep had the lowest mean MVC% between 1.79% - 5.16%. For all shots, the Forearm flexor had the lowest variation, and the Bicep had the greatest variation.

Downswing

During the downswing, there was a mean elbow angle of 150.72° for the cover, 146.66° for the lofted cover, 109.53° for the leg flick, and 96.3° for the straight drive. Variation was low between 2.52% - 16.38% with the leg flick and straight having greater variation again potentially due to the greater sample size. The different elbow angles indicate the batters orientating themselves to execute different motor patterns. Lead elbow angle in prior studies shows a less flexed elbow for straight drives with Stretch et al, (1998) reporting a mean front elbow angle of 117°. This may be due to the difference in the level of competition among participants as Stretch et al, (1998) measured provincial cricketers rather than adolescent school cricketers.

The lofted cover has a slightly more flexed elbow to allow greater extension at contact which results in the ball being elevated. The leg flick has a greater amount of elbow flexion as the batter must react to the differing line of the delivery and have less space for the extension of the elbow to apply force upon the ball. The straight drive has the greatest amount of elbow flexion of all shots measured and is 33.22° more flexed than the lofted straight drive. This may be due to the delivery being of a fuller length and landing closer to the batter's feet, resulting in the batter flexing their elbow more to adjust. Fuller deliveries may not allow batters to generate power by rotating their upper body as in the X-angle and would thus compensate through greater elbow extension to generate the bat speed however this is unclear and requires further investigation.

The Forearm flexor had the greatest mean MVC% for all shots, between 25.79% - 31.30% apart from the Leg flick which had an equal MVC% for the Forearm flexor at 28.20%. The Forearm extensor had the second highest mean MVC%, between 23.36% - 29.65% apart from the mentioned Leg flick and the Lofted cover whereby the Tricep had a greater mean MVC% than the Forearm extensor. The Bicep had the lowest mean MVC% for all shots, between 13.76% - 20.24%.

Moving from the backlift phase to the downswing phase the Forearm flexor was the muscle with the highest mean MVC% indicating a change in demands. There is also the beginning of a difference in muscle activation between the different shots as is seen in the differences in lead elbow angle. The increased flexion of the lead elbow for the Leg flick and Straight shot do not seem to result in different mean MVC% however do have greater variation for the Bicep which may be correlated to the lead elbow angle.

Contact

At contact, the mean elbow angle was 162.27° for the cover, 152.14° for the lofted cover, 123.50° for the leg flick and 148.64° for the straight drive. Variation increased from the downswing phase, particularly for the lofted cover (21.99%) and leg flick (37.50%). The mean elbow angle of straight drives indicates a more extended lead elbow in comparison to prior studies. Elliott et al, (1988) recorded a mean front elbow angle of 136° , Stretch et al (1998) a mean front elbow angle of 124° and Stuelken, Portus and Mason, (2005) recorded a mean front elbow angle of 116° . This may be due to the participants being instructed to perform lofted

straight drives resulting in the attempt to straighten the lead elbow more than would be typical for this shot.

The cover had a greater change in lead elbow angle at $+11.22^\circ$ compared to the lofted cover with a change of $+5.48^\circ$. In comparison the lofted straight drive had a change of $+23.92^\circ$ and the straight drive had a greater change of $+52.34^\circ$. The shots hit along the ground had a greater change in lead elbow angle which is linked to greater bat speed generation. It may be that batters are not attempting to control the bat angle as much for shots along the ground as speed has a greater advantage than precision in this case thus, they are free to use greater elbow extension. Whereas for lofted shots ball launch angle is directly related to the ball launch angle and thus greater control is needed to achieve an optimal bat angle resulting in less of a change in lead elbow extension.

For example, the lofted deliveries had similar elbow angles at impact with 153.44° for lofted straight drives and 152.14° for lofted cover drives. This may have been in to achieve the optimal ball launch angle. Contrastingly the drives along the ground have very different elbow angles at impact at 162.27° for the cover and 148.64° for the straight drive.

The greater amount of elbow extension for the cover shot hit along the ground as opposed to the elevated shot of the lofted cover seems to be opposite to expectations. Ball launch angle is found to be directly related to bat angle at impact and a greater amount of elbow extension should lead to a greater bat angle at impact resulting in ball elevation (McErlain-Naylor et al., 2021). The lofted cover however has less lead elbow extension to the cover shot and achieves elevation. The reason for this is unclear and may be due to differing orientations of the batter's other limbs such as foot placement and angle of torso.

The leg flick has the highest mean elbow flexion of shots that were included in the results and the greatest amount of variation. The flexed elbow may be due to the demands of hitting a ball to the leg side of the batter and the large amount of variation may be due to the small sample size and broader classification of this group. Whereas the other shots which are to the off-side or straight have greater separation over what classifies in that group the leg flick does not and is all shots to the leg side resulting in greater variation. Further research is needed on other classes of shots to build a better picture of their demands and orientation.

The Forearm extensor had the highest mean MVC% across all shots, between 42.35% - 58.23%, followed by the Tricep (42.15% - 45.07%) for all shots except the Straight drive where

the Forearm flexor (49.38%) had the second highest amount of mean MVC%. The Forearm flexor had the third highest mean MVC% for all shots (35.16% - 49.38%) except the above-mentioned Straight drive and the Bicep had the lowest mean MVC% for all shots, between 24.44% - 34.57%. The pattern of mean MVC% magnitude continues with the Forearm extensor having the highest mean and the Bicep having the lowest mean. The Forearm extensor had the lowest amount of variation of the Unsuccessful shots, between 27.89% - 45.81% whereas the Bicep had the greatest amount of variation, between 60.31% - 74.21%.

An example of this is the Straight drive which shows unique muscle activation. It had the highest mean MVC% of all shots, which occurred in the Forearm extensor. The straight drive also had the lowest variation for the Forearm extensor of all muscles for Unsuccessful shots. This indicates that this shot has a high demand for the Forearm extensor at contact, which may be a general pattern for the shot. It also had a higher mean MVC% for the Forearm flexor compared to other Unsuccessful shots. In contrast, Bicep activation had the lowest mean MVC% of all Unsuccessful shots and the highest variation.

There are no studies to the author's knowledge analysing the straight drive, preventing comparison of findings to prior studies. The off-drive and on-drive analysis shows the differing mean elbow flexion batters can use. At impact, Elliot et al (1993) recorded mean lead elbow angles of 136° and mean rear elbow angles of 115° (Table 5). A higher amount of flexion compared to Stuelcken, Portus and Mason, (2005) with a mean lead elbow angle at impact of 116° and a mean rear elbow angle at impact of 98° (Table 5). The differing mean rear elbow angles may be an indication of the amount of variation of Bicep MVC% as batters have varying techniques and adapt to each delivery. There is still a large amount of variation within the shot pattern; further research is needed on this shot.

The Leg flick also has unique activation patterns with the highest mean MVC% for the Bicep, potentially indicating a greater need compared to other Unsuccessful shot types. Tricep mean MVC% is similar for all shots due to the muscle having a general demand across all shots. This may be due to the lead elbow extension from downswing to impact as shown in prior studies (Table 4, Table 5).

Follow-through

During the follow-through phase mean elbow angle was 149.85° for the cover, 141.59° for the lofted cover, 138.69° for the leg flick and 147.20° for the straight drive. Variation decreased

from contact and was low at between 4.01% - 13.17% with the leg flick having the greatest amount of variation. The similar elbow angles and decreased variation indicate a general trend for elbow angle during the follow-through phase. This may indicate that batters move towards their general trend of motor patterns regardless of the shot outcome. The lead elbow angle was more flexed in this study than in prior studies where Stretch et al (1998) measured a front elbow angle of 125° for front foot drives.

The Forearm extensor had the highest mean MVC% for all muscles in Unsuccessful shots, between 27.35% - 38.97%. From Contact the Tricep decreased in activation from having the second highest amount of activation to the third highest amount of activation as the Forearm Flexors moved up to having the second highest amount of activation. The Forearm flexor had a mean MVC% of between 23.68% - 31.78%, the Tricep had a mean MVC% of between 19.14% - 24.43% and the Bicep had the lowest mean MVC%, between 12.88% - 21.50%.

This indicates that the forearm has a greater demand in the shots measured than the upper arm. The Straight drive had greater mean forearm activation in comparison to the other shots which may indicate greater demands.

The greater amount of forearm activation is due to the cocking motion of the wrist as batters can accelerate the bat through a greater ROM. The straight drive is where this is particularly evident as batters do not extend the elbow as much as a lofted drive and thus may have a greater amount of wrist uncocking to maximise bat speed.

Penn and Spratford show the belief of a segment of levers for drives aimed at timing whereas Peplow shows the uncocking of the wrist as greater than the lead elbow extension (almost double). With the aim of hitting a lofted drive batters adapt to the variation of the delivery from the bowling machine. This is the reason for the variation during delivery.

Summary of batting phases

The higher demand of the forearm extensor across all phases for both successful and unsuccessful shots indicates a potential need for endurance and power in this muscle group as batters will have to sustain the activation for the duration of the innings. Lateral elbow epicondylitis is a chronic non-contact injury occurring in the forearm extensors (Pardiwala, Rao and Varshney, 2017; Mitchel and Whited, 2022). The high demand on the forearm extensors indicates a potential for injury although the low injury rates may indicate that it is

only applicable to certain batters (Dhillon et al., 2012). As such coaches should identify players at risk of this chronic use injury to prevent it occurring. Chronic use injury such as elbow lateral epicondylitis may not lead to time loss injuries but may instead reduce batter performance.

For successful shots, the tricep had the greatest activation at contact with an increase in activation from the downswing phase, indicating the potential need for explosive force in this muscle. Further research is needed to determine if targeting these muscles may result in a difference in batter performance.

The differing demands of the unsuccessful shots may have an impact on players who score through specific areas, for instance, if a player scores by hitting more straight drives there is a higher amount of muscle activation. This player may fatigue at a faster rate due to the higher amount of activation however future research is needed to determine if that is the case.

5.2 SIGNIFICANTLY DIFFERENT PARTICIPANTS

Three general patterns can be seen amongst participants and three participants were found to be significantly different to the other participants.

General patterns:

1) The LBBT batters had greater forearm activation in comparison to upper arm activation during the downswing phase. SBBT batters had greater upper arm activation in comparison to forearm activation.

2) At contact Participants Two, Four, Seven and Nine had the greatest activation in the triceps, this may be because they extended their elbows until almost straight. These players may not be 'wristy' players as they may not have a great amount of wrist flexion to generate bat speed.

3) At contact Participants Three, Five and Eight have the greatest activation in the forearms and have less extended elbows. These participants may be called 'wristy' and may have a greater amount of wrist flexion to generate bat speed. These participants have a similar lead elbow angle to elite female cricketers who used a greater amount of wrist flexion to generate bat speed (McErlain-Naylor et al., 2021). It is unclear if that were the case in this study and whether the female cricketers would have had a higher MVC% in the forearms is unclear. This must be determined in future studies.

Participant 10 extends the elbow until almost straight and yet has high forearm activation. When analysing the film, it can be seen that this participant extended their elbow, and had a large amount of wrist extension and a large amount of torso rotation (X-angle). This participant exhibits all of the kinematic parameters linked to greater bat speed generation and ball carry distance and may be highly proficient at playing the lofted straight drive.

What makes them different:

1) Participant Eight had a significantly lower mean lead elbow angle in comparison to the other participants. This is particularly present during the backswing phase (Table 15) and the follow-through phase (Table 18). This participant had less activation in the upper arm in comparison to the forearm which may be due to the lower amount of lead elbow extension. As a result, the participant may have greater wrist flexion and torso rotation such as the X-angle however this was not measured and so cannot be said for certain. Upon investigation of video footage and stills such as that displayed in Figure Three (page 40), it is the opinion of the author that this may be the case.

It is unclear whether this participant should aim to alter their technique by flexing their elbow more during the backswing phase or should look to maximise their unique technique. This can potentially be done in two ways: by creating a physical training program aimed at fatigue resistance in the forearms or by altering their approach to the game to maximise scoring in shots that do not have a large amount of elbow extension or tricep activation such as avoiding the straight drive. This can be determined in future research or by an elite coach in partnership with the player.

2) Participant Four had a significantly lower mean forearm flexor MVC% in comparison to the other participants. This is interesting as the participant has the highest mean MVC% for the downswing phase (Table 16) and yet the lowest MVC% for the contact phase (Table 17) and the follow-through phase (Table 18). This may be due to ensuring control of the top hand to avoid bat deviation upon contact and not increase due to the participant not having a large amount of wrist flexion. This may be due to the participant using an SBBT and thus having a greater amount of lead elbow extension to generate bat speed. The participant may not have a large amount of wrist flexion and may have a large amount of torso rotation or X-factor however this was not measured and so cannot be determined. Upon investigation of video

footage and stills (Figure One), it is the opinion of this author that this participant has a large X-factor and does not have a large amount of wrist flexion.

It is unclear whether this participant should aim to alter their technique by having a greater amount of wrist flexion or if the player should aim to maximise their unique technique. This can be done in two ways: by creating a training program that increases the explosive force of the tricep to maximise their large elbow extension or; by adapting their game to include more controlled shots without the added bat speed of wrist flexion and instead aiming to time the shot and make contact within the 'sweet spot'. This can potentially be determined by future research or by an elite coach in partnership with the player.

3) Participant Nine had a significantly lower mean forearm extensor MVC% in comparison to the other participants. This can be seen at the moment of contact (Table 17) and during the follow-through phase (Table 18). This may be due to the participant not having a large amount of wrist flexion and having a full follow-through thus avoiding resisting the bottom hand in a figure nine position. This may be due to the participant using an LBBT and thus having a lower amount of forearm extensor activation during the backswing phase. The participant did not flex their elbow by a great amount and did not have a large amount of mean MVC% in comparison to the other participants. They, therefore, could be relying on a large amount of torso rotation or X-angle to generate bat speed. Upon investigation of video footage and stills (Figure Four), it is the opinion of this author that this participant has a large X-angle and does not have a large amount of wrist flexion.

It is unclear whether this participant should aim to alter their technique by increasing the wrist flexion and 'cocking' of the wrist during the backswing phase. Whether the participant would increase bat speed by adopting more wrist 'uncocking' or by extending their elbow more cannot be determined in this study. This can be investigated in future studies.

Concluding comments

Prior research has observed batter kinematics and biomechanics to understand how batters perform respective shots and what is important for the successful outcome of these shots. To understand the techniques, they have applied terms such as the 'lateral backlift technique' to distinguish and study them in more detail. Once the techniques were characterized, they were studied to see what was important for their success such as the kinematic study determining key parameters linked to bat speed generation. With knowledge such as a higher proportion of

elite batters use the lateral backlift technique' and 'lead elbow extension, wrist uncocking and a higher X-angle are linked with greater bat speed generation'. It is tempting to suggest all batters should use the lateral backlift technique and they must aim to have a large X-angle, lead elbow extension and wrist uncocking.

This ignores the unique batters that exist within cricket and the subtle differences between all cricket batters. In this study, there were three participants found to be significantly different from the rest of the sample. These participants can be grouped within the definitions prior research has provided and they do use the kinematic parameters important for bat speed generation however they are unique from the rest of the sample. This indicates a need to assess each batter as an individual.

This study does not use an objective measure of batting 'success' and is thus descriptive. Patterns can be described amongst batters from the lateral and straight bat backlift technique which may assist in the creation of a general training program addressing the muscles observed to have the higher mean activation in this study. This must be balanced with the individual techniques of batters

CHAPTER 6

CONCLUSION

6.1 SUMMARY OF RESULTS

The first aim of the thesis was statistically disproven as no specific shot was shown to have a different batter lead elbow angle or muscle activation. The second aim was proven statistically significant indicating particular demands for the batting phases as seen in the results.

At the backswing phase, there was a low amount of inter and intra-participant variability with the lateral and straight backlifts having different activation patterns. Batters using the lateral backlift technique had a higher amount of activation in the forearms during downswing whereas straight backlift technique batters had higher tricep activation. This is due to the straight backlift requiring batters to extend their elbow to generate bat speed whereas lateral backlift batters may use more torso rotation and wrist uncocking.

During the downswing batter muscle activation increased rapidly with a high amount of variability due to the need to adapt to the variation of each delivery. At contact, the tricep had the highest mean activation followed by the forearm extensors. The forearm extensor had the highest mean activation throughout all phases indicating it may have a high demand when batting and must be targeted for fatigue resistance.

The third aim was found to be statistically significant indicating that batters can have a unique technique with differing lead elbow angles and muscle activation compared to the rest of the sample. Overall, this study provides greater insight into cricket bat speed kinematics allowing coaches and players to better understand their technique with potential benefits as the result of future research.

6.2 RESEARCH HYPOTHESES

6.2.1 Hypotheses 1:

There was no difference in lead-elbow angle or MVC% based on shot type across all participants, thus accepting the null hypotheses.

6.2.2 Hypotheses 2:

There was a difference in lead elbow angle and MVC% between participants, thus rejecting the null hypotheses.

6.2.3 Hypotheses 3:

There was a difference in lead-elbow angle and MVC% based on the batting phase across all participants, thus rejecting the null hypotheses.

6.3 LIMITATIONS

The major limitation of this study is the lack of an objective measure that has been linked to performance in prior studies such as bat speed, magnitude of X-angle and other kinematic measures. The small sample size is another limitation, and it is suggested that future studies focus on larger samples to obtain more representative data.

An accelerometer was attached to the toe of the bat and recorded data that could potentially be converted to bat speed. However, the researchers were unable to convert the data to bat speed. Pilot studies aimed to establish the magnitude of the X-angle however marker occlusion due to a limited number of cameras in the department prevented stable data recording and so it was not used for testing. Due to the marker occlusion other kinematic variables were not used for the study. The benefit of these objective measures is that they would allow inference of the potential effects of MVC% on performance measures such as bat speed and ball carry distance through findings in prior studies. This is a limitation in the applicability of the findings in this study however the descriptive side of the findings identifies future recommendations for research. Batter technique classification through video footage did not use a vector method to add to the accuracy of the study and this is a limitation. Future studies should use this if not a kinematic study using motion capture, to ensure accuracy, reliability and repeatability.

6.4 RECOMMENDATIONS

Due to issues with the accelerometer and motion capture technology, this was a descriptive study proposing potential adjustments to training to improve batters within their technique. These recommendations depend on an objective measure of batter success to determine what level of importance the findings carry. This is the greatest need for future research as a reliable measure of bat speed will aid in the understanding of what is important for each batter. This should also be done in a more representative testing scenario as bowling machines are shown to alter batting kinematics and the lofted straight drive was the only shot of focus. Throw-downs offer greater representative results or measurements of live bowling with ball tracking for ball delivery location should be used in future studies. Using these methods to create a simulation of an innings can determine which shots particular batter's favour to score and profile how they achieve this with the objective measure for comparison.

The sample must also be broadened as a small sample of adolescent batters does not represent the wider population of batters in cricket. Looking at the data there is evidence for treating batters individually which indicates the need to repeat the protocol with a greater sample size and profile a more diverse player group such as more than one left-hand batter. When considering the differences in kinematics between men and women this indicates a need for female batters to be studied. This is needed to understand why kinematic differences exist between the sexes if the differences are present during adolescence, how this relates to performance for women specifically and if women should be coached differently from men.

In addition to the need for greater information on batters to determine the key mechanisms linked to their technique that can lead to success, it is important to determine how these technical aspects can be improved. Areas of interest for the future are whether a physical training protocol aimed at explosive lead arm tricep movement improves bat speed and whether forearm extensor fatigue resistance can lead to fewer movement errors. Due to the high forearm extensor activation and the potential for lateral elbow epicondylitis future studies can investigate the link to potential injuries.

6.5 CONCLUSION

The study objective was to determine if differences in batter lead elbow angle and muscle activation occurred based on shot type, batting phase and/or between participants. The study did not determine differences between shot types due to the small sample size and limited scope of lofted straight drives. Differences were found between the batting phases and between participants. Differences between batting phases indicate that they have different demands applied across all shot types measured in this study.

Higher demands on forearm extensors across all phases indicate the need for fatigue resistance. Strength exercises such as a barbell wrist roller where a weighted barbell is rotated between hands by extending the wrist extensors can increase fatigue resistance. Rapid increases in activation of the forearm flexors and triceps brachii from downswing to contact indicate the need for explosive movements. Strength exercises such as wrist flexor curls and narrow grip barbell bench presses can improve explosive power in these muscles.

Differences between participants indicate that adolescent male batters must be treated individually as they may not present with the exact techniques that have been described in prior research. Understanding of the individual technique of batters and how to support that technique with physical training may aid in batter performance. Greater sample sizes and objective measurements of shot outcomes such as bat speed or ball carry distance are needed to add to the findings of the study.

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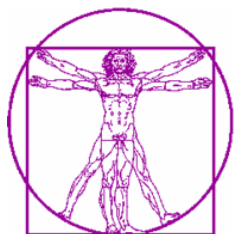
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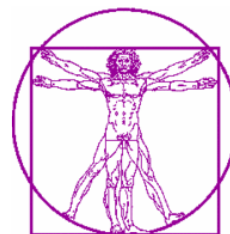
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APPENDIX 1

INFORMATION TO PARTICIPANTS



RHODES UNIVERSITY
Grahamstown • 6140 • South Africa



HUMAN KINETICS AND ERGONOMICS

Contact information:

Name: Ryan Mc Carthy

Cell number: 072 476 2500

E-mail: ryanmccarthy1253@gmail.com

Dear _____

Thank you for volunteering to participate in the research currently being conducted. Your help and participation are greatly appreciated.

Title of thesis

Descriptive Study Of Cricket Batting Mechanics

Aims of the study

Cricket has received very little research attention and in particular, there are no known studies on muscle activation of the upper limbs of cricket batters. Observation of cricket batter upper limb muscle activation using EMG during a distance hitting protocol may provide important knowledge for coaching practices and allow a greater understanding of individual batter performance.

The purpose of this study is to identify muscle activation of the upper limbs of cricket batters in the hope that future studies may use this information to benefit cricket batters. Therefore, this is an explorative, descriptive study on the muscle activation of the upper limb in adolescent cricket batters.

Procedures

Once you have signed an informed consent form, an information session will be scheduled to better explain the testing procedures which will be used. In participating in this study, you will be anonymous, your identity will not be shared and you may withdraw from the study at any time. Session two will be scheduled where basic demographic information will be obtained (age, sex) as well as participant height and weight. Participants will also be habituated with the equipment (EMG) in this session.

A date will be established for testing. On the testing day, the EMG will be set up as indicated in the protocol, and participants will complete a warm-up and complete the testing protocol.

Risks

The risks are potential for injury or that data may be leaked to the public however precautions have been put in place to stop this from happening. The strain induced will be similar to the strain experienced when training and thus should not cause any injuries. The main potential for injury is due to impact with the ball however participants will use their protective equipment and the throw-downs will be at a representative speed that will not exceed typical demands for participants. To protect the identity of the participant all data will be confidential and will be coded by the researchers.

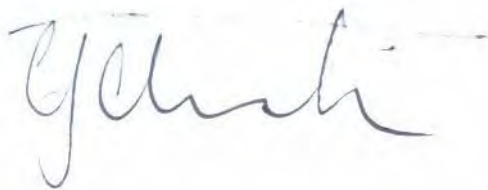
Benefits

The benefits of the study will allow you to have a greater understanding of the physical demands of the game and you will be contributing to an original study establishing information that has not been known before. The information obtained from this study can inform future studies creating training programs to reduce injury risk or increase performance.

Other

If there are any queries or questions, please do not hesitate to contact us at any time. Photographs may be taken for illustration purposes, but these will remain anonymous. If at any time players feel the need to withdraw from the study due to personal reasons, they may do so without any consequence or action.

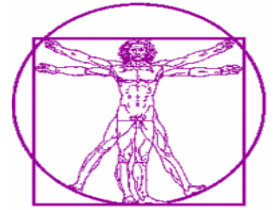
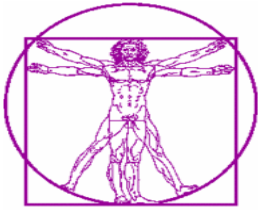
Regards

A handwritten signature in blue ink, appearing to read 'Candice Christie', with a horizontal line extending to the right.

Prof Candice Christie (Primary investigator)

Ryan Mc Carthy

PARTICIPANT, PARENT/GUARDIAN AND COACH CONSENT FORM



RHODES UNIVERSITY

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Human Kinetics and Ergonomics Department

INFORMED CONSENT AND INDEMNITY

For research involving human participants

I, have been fully informed of the research project entitled:

Descriptive Study Of Cricket Batting Mechanics

I have read the information sheet and understand the testing procedure that will take place. All testing procedures, associated risks and the benefits of partaking in this study have been explained to me in writing [*letter of information appended to this document*]. I have had ample opportunity to ask questions and to clarify any concerns or misunderstandings. I am satisfied that these have been answered satisfactorily. I understand that all data collected for publication purposes will be kept anonymous and all information gained in this regard will be treated confidentially. I understand that I can withdraw from the study at any point, irrespective of external influences placed on me by the researcher.

In agreeing to participate in this research study I waive any legal recourse against the researchers from the Department of Human Kinetics and Ergonomics (HKE), Rhodes University, from claims resulting from personal injuries sustained whilst participating in the above-mentioned research. I am aware and fully understand that the Department of Human Kinetics and Ergonomics is not responsible for any injuries due to my personal negligence and non-compliance with instructions. This waiver shall be binding upon my heirs and personal representatives. In terms of assent, the research staff will watch your child for signs of being upset, such as whining, crying, or struggling. If your child becomes upset we will stop the session for a short break of 5-10 minutes. If he or she remains upset, we will stop the sessions for that day. I have read and understood the above information, as well as the information provided in the letter accompanying this form. I therefore consent to voluntarily participate in this research project.

GUARDIAN:

(Print Name) (Signed) (Date)

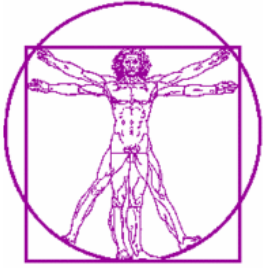
COACH:

(Print Name) (Signed) (Date)

PARTICIPANT:

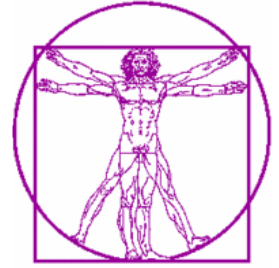
(Print Name) (Signed) (Date)

PARTICIPANT ASSENT FORM



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Human Kinetics and Ergonomics Department

ASSENT SCRIPT

For research involving human participants

TITLE OF THE RESEARCH PROJECT: Descriptive Study Of Cricket Batting Mechanics

RESEARCHERS NAME(S): Professor Candice Christie, Andrew Todd, Luke Goodenough (M.s.c) and Ryan Mc Carthy (M.s.c candidate).

ADDRESS: Department of Human Kinetics and Ergonomics, Upper African Street, Grahamstown, 6139

CONTACT NUMBER: 046 603 8471

What is RESEARCH?

Research is something we do to find new knowledge about the way things (and people) work. We use research projects or studies to help us find out more about disease, illness or fitness. Research also helps us to find better ways of helping children become physically fit and active or treating children who are sick.

What is this research project all about?

This study will look at what muscles in the arms and shoulders are used when batting in cricket. If we know this information we can design programs that will help you perform better and reduce your risk of becoming injured or hurt.

Why have I been invited to take part in this research project?

You have been invited to take part in this research as there is limited work that has looked at this area and little cricket research on players of your age. By doing this project you will be helping not only yourselves, but also all cricket batters and other people of your age.

Who is doing the research?

The research is been done by Candice, Andrew, Luke and Ryan- we work at the Human Kinetics and Ergonomics Department at Rhodes University and are doing this project to help with your practices and match training.

What will happen to me in this study?

Nothing bad will happen to you by helping us in this study. We will be putting surface electrodes on you and asking you to complete a typical practice scenario. The surface electrodes are non-invasive and will be stuck onto specific areas of your arms and shoulders to measure muscle activity as you bat. Using the surface electrodes will not be painful and the training scenario will not be stressful. You will have time to be introduced to the equipment and may withdraw from the study at any time.

Will anyone know I am in the study?

You and your teammates will be involved in this study (if you want to), but you can pull out at any time. Also, all the information that we collect from you will be kept confidential which means that no one will know it is your information.

Who can I talk to about the study?

If you have any questions you can phone Candice, Luke or Ryan at the HKE department (046 603 8471)

What if I do not want to do this?

Even if your parents have agreed to your participation you may refuse to take part in this study, even though it may benefit you. You can also stop being in the study at any time without getting in trouble.

Do you understand this research study and are you willing to take part in it?

 YES NO

Has the researcher answered all your questions?

 YES NO

Do you understand that you can pull out of the study at any time?

 YES NO

Signature of ChildDate

- Data obtained from the study will be archived. Two copies of the data collected will be stored by the researcher and their supervisor in a digital format as well as a hard copy of the processed data. The data will be stored indefinitely for publication purposes. Player anonymity will be protected in the form of coding and names will not be released to any people other than the researcher and

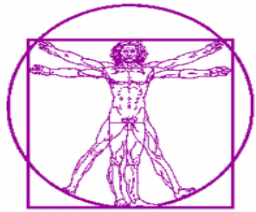
their supervisor. If any pictures are taken distinguishing features will be blocked out.

With regards to research being conducted on private property:

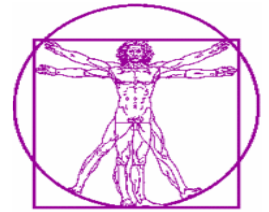
- The research will be conducted at the Human Kinetics and Ergonomics department at Rhodes University, Grahamstown, South Africa. Consent will be obtained from those responsible and testing will not interfere with any school activities that may occur during the testing period. The tester will also acknowledge that they will be using the facilities at their own risk and will pay for any damages or breakages that may occur due to the protocol being performed on the private property of the University.

APPENDIX 2

PARTICIPANT 1



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Feedback from Arm Muscle Activation Study

Kinematic studies (measuring human motion) show key movements for generating bat speed in cricket batters to be elbow extension, wrist uncocking and the 'X-angle' (Peploe et al., 2019). Elbow extension is how flexed or straight the batter's lead arm (left arm for a right-handed batter) is during the shot. For example, if a batter straightens their arm more in a shot it has been found to generate more bat speed. Wrist uncocking (wrist flexion) is the movement of the wrist by lifting the hand up and down at the wrist joint when the forearm is stable. X-angle is torso rotation whereby, the more a batter rotates the shoulder and rib cage in comparison to their hips, the higher the bat speed generated (Peploe et al., 2019). Higher bat speed correlates to greater ball carry distance which is important for hitting boundaries (Taliep and Gray, 2010; Peploe et al., 2018).

This study aims to determine the patterns of muscle activation in the muscles moving elbow extension and wrist uncocking. The main muscle in elbow extension is located on the rear of the upper arm (triceps). The main muscle group involved in wrist uncocking is located on the underside of the lower arm (forearm flexors). In the body when a muscle activates to produce a movement it is termed the agonist, this then produces a reaction in the muscle on the opposite side of the limb which is termed the antagonist. The antagonist for the tricep is located on the front of the upper arm (bicep) and the antagonist for the forearm flexors is located on the top of the lower arm (forearm extensor).

Knowledge of the muscle activation of agonist and antagonist muscles is important to gain a greater understanding of the movement at the joint. For example, a study measuring the muscle strength of cricket batters found that batters with greater

stability around the shoulder joint are more likely to have a higher batting average (Nunes and Coetzee, 2007). Muscle activation is measured using electromyography which measures the electrical signal sent to the muscles from the brain (Basmajian and DeLuca, 1985). What is important in this study is not the amount of muscle activation but the amount sent to each muscle at different points of the cricketing shot.

For instance, if a player has a higher percentage of muscle activation in the triceps during the downswing of their shot then this is the main muscle mover producing bat speed. Another player may have a higher percentage of muscle activation in the wrist flexors during the downswing of their shot meaning that this is the main muscle mover producing bat speed for them. Building an understanding of how each batter utilises their muscles allows a greater understanding of how a batter produces their bat speed leading to individual training programmes.

The training programme can allow improved force production, leading to greater bat speed without disrupting the natural technique of the batter.

Batting phases

In cricket batting, the shot is divided into six phases: Stance and initial movement, backlift, stride, downswing, contact and follow-through (Peploe et al., 2018). The main phases of interest in this study are backlift, downswing, contact and follow-through. In the graphs below contact with the ball occurs at 0.8s, the time following which is follow through. Downswing is distinguished per shot and backlift is determined as the time before this.

Muscle activation patterns

Muscle activation of 0-30% is low, activation of 31-50% is moderate, 51-70% is moderately high and 71-100% is high. High activation means that the majority of the muscle fibres that are measured are active and producing a muscular force. Muscle activation cannot directly be compared to force so maximum activation does not mean maximum force but it does mean that the entire muscle is active. A higher activation in a movement means that the muscle has a high demand to produce that movement. The muscle that has a higher demand placed upon it should be the target of a strength and conditioning programme to better prepare it for the demands.

Forearm extensor

The forearm extensor muscles are involved in lifting the wrist upwards, ('cocking' the wrist) and in stabilising the wrist when impact is made with the ball. Cocking the wrist allows lifting the bat during the backswing and wrist stabilising helps keep the bat from twisting out of the hand when it hits the ball.

Forearm flexor

These muscles are involved in pulling the wrist downwards, also known as 'uncocking' the wrist and in stabilising the wrist when impact is made with the ball. Uncocking the wrist leads to more bat speed as the bat is pushed forward towards the ball.

Bicep

The biceps flex the arm at the elbow, this helps lift the bat during backlift and stabilises the arm in the shot.

Tricep.

The tricep extends the arm at the elbow which increases bat speed as the bat is moved towards the ball.

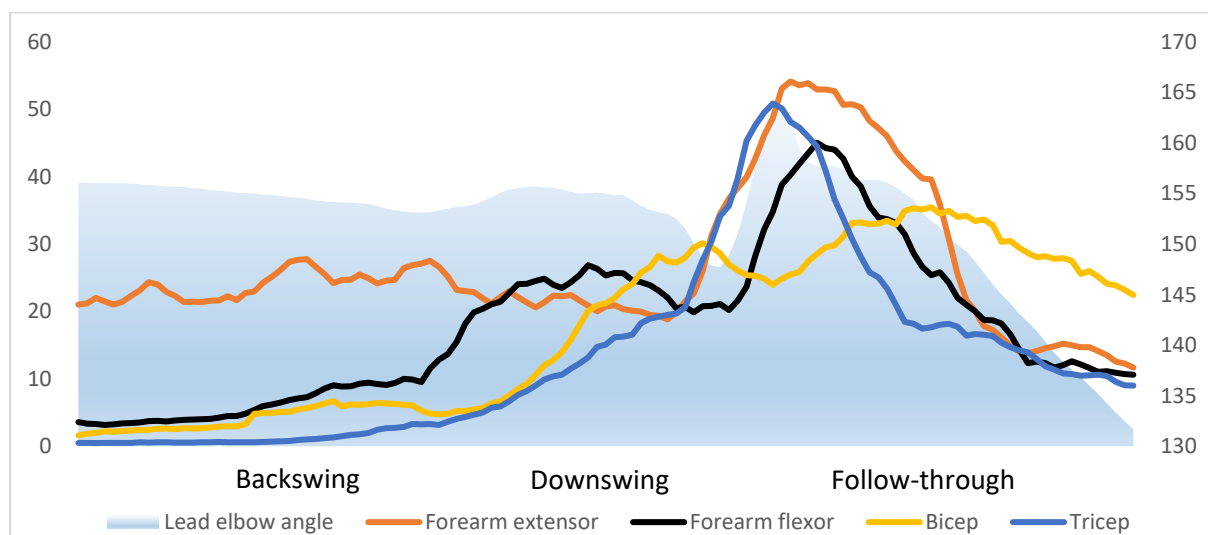


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 150° on the

right axis as the participant flexed/bent their arm in preparation to hit the ball. This then increases up to 165° as they extend/straighten their arm to peak at contact. The point where the blue shading and tricep (blue line) reach their peak is the moment of contact with the ball. This makes sense as the tricep is the main muscle used to extend/straighten the arm and this is found to be important for bat speed generation.

As the participant bends their arm the Forearm flexor (black line) decreases in activation. It may be that the participant was squeezing the bat in anticipation of the delivery, relaxed as they reacted to play the shot and then increased again to gain control of the bat. Wrist uncocking is a contributor to generating bat speed which uses the wrist flexors and does not appear to be this participant's way of generating bat speed. The participant can work with a coach on trying to add or increase this into their game or focus on what works for them meaning that more 'wristy' shots such as a leg-side flick off of the pads may not be a main scoring shot for them, rather preferring to extend their elbow and bat through the ball.

The Forearm extensor (orange line) has the highest average activation and as such has a higher demand compared to the other muscles. This can be seen in the downswing with the cocking of the wrist and at contact, into follow-through. The reason for this is largely control of the bat. If you lift your left hand and bend it sideways, towards your thumb this will simulate the movement made when batting as you resist the force of the bottom hand and bat pushing on it. This repetitive force can cause fatigue which can lead to decreased control during batting.

Common themes

You use a straight bat-backlift technique. Backlifts in cricket can be separated into two categories of techniques, the Lateral backlift technique and the Straight bat backlift technique (Noorbhai and Noakes, 2016). The lateral backlift is where the bat is angled further than the conventional 25° from the centre of the pitch whereas a straight backlift with the bat in line with the wicketkeeper (Stuelcken, Portus and Mason, 2005; Noorbhai and Noakes, 2016).

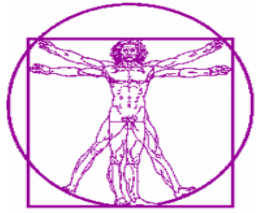
This means that during the backswing you bend your elbow more to get the bat higher and help generate more bat speed during the downswing, extending your elbow into the shot and rotating your chest to increase bat speed. It means that you have a higher

amount of tricep activation when batting as this may be more important for you to generate higher bat speeds. Focusing on increasing the explosive power of your tricep which increases in activation rapidly during downswing and core power for rotation may help in generating bat speed. This must be balanced with fatigue resistance of the forearm extensors to keep your technique controlled and reduce movement variability which increases with fatigue.

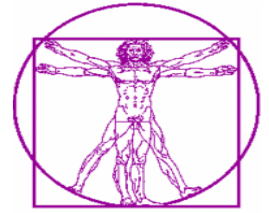
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PARTICIPANT 2



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Forearm extensor

The forearm extensor muscles are involved in lifting the wrist upwards, ('cocking' the wrist) and in stabilising the wrist when impact is made with the ball. Cocking the wrist allows lifting the bat during the backswing and wrist stabilising helps keep the bat from twisting out of the hand when it hits the ball.

Forearm flexor

These muscles are involved in pulling the wrist downwards, also known as 'uncocking' the wrist and in stabilising the wrist when impact is made with the ball. Uncocking the wrist leads to more bat speed as the bat is pushed forward towards the ball.

Bicep

The biceps flex the arm at the elbow, this helps lift the bat during backlift and stabilises the arm in the shot.

Tricep.

The tricep extends the arm at the elbow which increases bat speed as the bat is moved towards the ball.

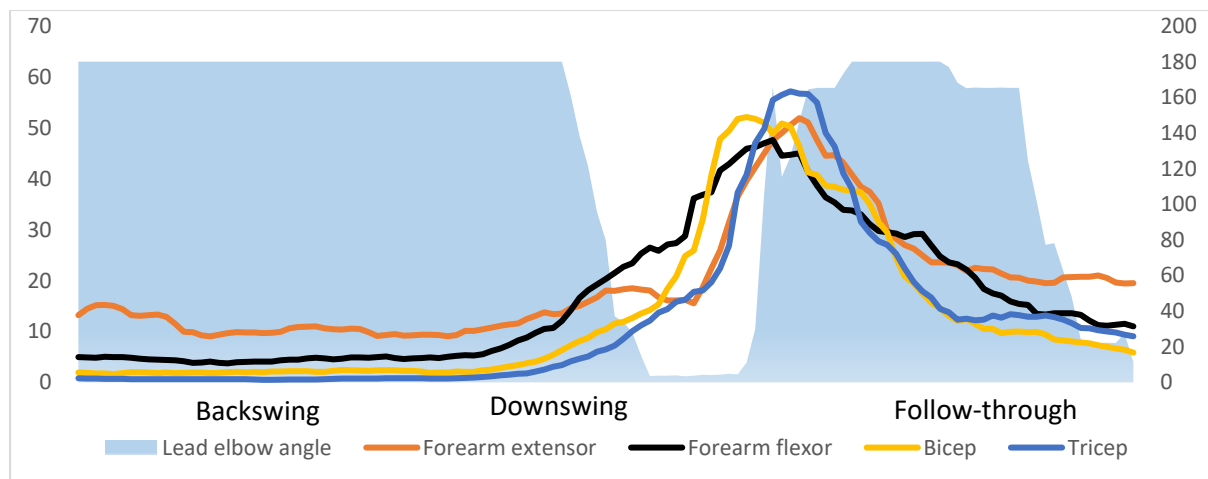


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 5° on the right axis as the participant flexed/bent their arm in preparation to hit the ball. This then

increases up to 165° as they extend/straighten their arm to peak at contact. The point where the blue shading and tricep (blue line) reach their peak is the moment of contact with the ball. This makes sense as the tricep is the main muscle used to extend/straighten the arm and this is found to be important for bat speed generation.

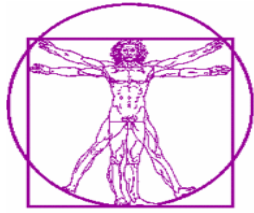
The bicep (yellow line) increases to have the highest activation during the downswing. This may be due to the bending of the lead arm as the bicep decreases in activation as the elbow is extended into contact. The forearm muscles have a high amount of activation throughout the shot, this may be an indication that the participant uses wrist extension throughout the shot to generate bat speed.

Overall, all muscles increase in activation up to the point of contact indicating a balanced approach with no one muscle in particular having a higher demand. With a moderate to moderately high amount of activation for all muscle groups measured a general program of fatigue resistance is recommended with emphasis on the tricep for explosive power.

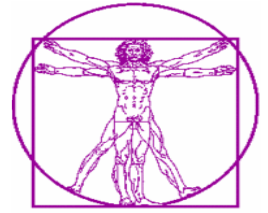
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PARTICIPANT 3



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Feedback from Arm Muscle Activation Study

Kinematic studies (measuring human motion) show key movements for generating bat speed in cricket batters to be elbow extension, wrist uncocking and the 'X-angle' (Peploe et al., 2019). Elbow extension is how flexed or straight the batter's lead arm (left arm for a right-handed batter) is during the shot. For example, if a batter straightens their arm more in a shot it has been found to generate more bat speed. Wrist uncocking (wrist flexion) is the movement of the wrist by lifting the hand up and down at the wrist joint when the forearm is stable. X-angle is torso rotation whereby, the more a batter rotates the shoulder and rib cage in comparison to their hips, the higher the bat speed generated (Peploe et al., 2019). Higher bat speed correlates to greater ball carry distance which is important for hitting boundaries (Taliep and Gray, 2010; Peploe et al., 2018).

This study aims to determine the patterns of muscle activation in the muscles moving elbow extension and wrist uncocking. The main muscle in elbow extension is located on the rear of the upper arm (triceps). The main muscle group involved in wrist uncocking is located on the underside of the lower arm (forearm flexors). In the body when a muscle activates to produce a movement it is termed the agonist, this then produces a reaction in the muscle on the opposite side of the limb which is termed the antagonist. The antagonist for the tricep is located on the front of the upper arm (bicep) and the antagonist for the forearm flexors is located on the top of the lower arm (forearm extensor).

Knowledge of the muscle activation of agonist and antagonist muscles is important to gain a greater understanding of the movement at the joint. For example, a study measuring the muscle strength of cricket batters found that batters with greater stability around the shoulder joint are more likely to have a higher batting average (Nunes and Coetzee, 2007). Muscle activation is measured using electromyography

which measures the electrical signal sent to the muscles from the brain (Basmaijian and DeLuca, 1985). What is important in this study is not the amount of muscle activation but the amount sent to each muscle at different points of the cricketing shot.

For instance, if a player has a higher percentage of muscle activation in the triceps during the downswing of their shot then this is the main muscle mover producing bat speed. Another player may have a higher percentage of muscle activation in the wrist flexors during the downswing of their shot meaning that this is the main muscle mover producing bat speed for them. Building an understanding of how each batter utilises their muscles allows a greater understanding of how a batter produces their bat speed leading to individual training programmes.

The training programme can allow improved force production, leading to greater bat speed without disrupting the natural technique of the batter.

Batting phases

In cricket batting, the shot is divided into six phases: Stance and initial movement, backlift, stride, downswing, contact and follow-through (Peploe et al., 2018). The main phases of interest in this study are backlift, downswing, contact and follow-through. In the graphs below contact with the ball occurs at 0.8s, the time following which is follow through. Downswing is distinguished per shot and backlift is determined as the time before this.

Muscle activation patterns

Muscle activation of 0-30% is low, activation of 31-50% is moderate, 51-70% is moderately high and 71-100% is high. High activation means that the majority of the muscle fibres that are measured are active and producing a muscular force. Muscle activation cannot directly be compared to force so maximum activation does not mean maximum force but it does mean that the entire muscle is active. A higher activation in a movement means that the muscle has a high demand to produce that movement. The muscle that has a higher demand placed upon it should be the target of a strength and conditioning programme to better prepare it for the demands.

Forearm extensor

The forearm extensor muscles are involved in lifting the wrist upwards, ('cocking' the wrist) and in stabilising the wrist when impact is made with the ball. Cocking the wrist allows lifting the bat during the backswing and wrist stabilising helps keep the bat from twisting out of the hand when it hits the ball.

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Tricep.

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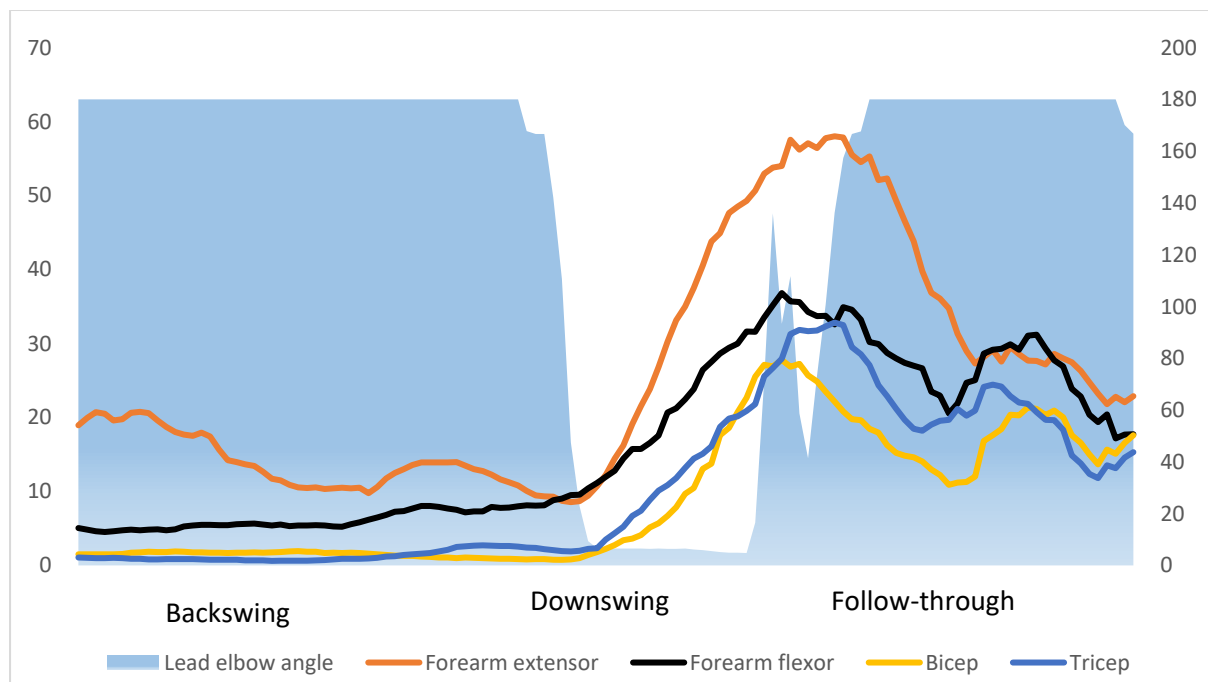


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 15° on the right axis as the participant flexed/bent their arm in preparation to hit the ball. This then increases up to 143° as they extend/straighten their arm to peak at contact. The point where the blue shading and forearm flexor (black line) reach their peak is the moment of contact with the ball. This makes sense as the forearm flexor is a muscle used to flex the wrist and this is found to be important for bat speed generation.

The forearm extensor (orange line) has the highest amount of activation, this may be due to cocking the wrist during backlift into the downswing and then uncocking it into contact to generate bat speed. This in addition to the forearm flexor (black line) peaking at contact may mean that this is the major way that you generate bat speed.

Another reason for the high forearm activation is largely control of the bat. If you lift your left hand and bend it sideways, towards your thumb this will simulate the movement made when batting as you resist the force of the bottom hand and bat pushing on it. This repetitive force can cause fatigue which can lead to decreased control during batting.

Common themes

You use a straight bat-backlift technique. Backlifts in cricket can be separated into two categories of techniques, the Lateral backlift technique and the Straight bat backlift technique (Noorbhai and Noakes, 2016). The lateral backlift is where the bat is angled further than the conventional 25° from the centre of the pitch whereas a straight backlift with the bat in line with the wicketkeeper (Stuelcken, Portus and Mason, 2005; Noorbhai and Noakes, 2016).

This means that during the backswing you bend your elbow more to get the bat higher and help generate more bat speed during the downswing, extending your elbow into the shot and rotating your chest to increase bat speed. Another way to generate bat speed is to extend your elbow more and this will increase your tricep activation.

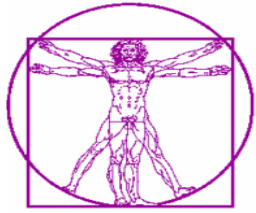
Focusing on increasing the explosive power of your tricep which increases in activation rapidly during downswing and core power for rotation may help in generating bat speed. This must be balanced with fatigue resistance of the forearm extensors to keep

your technique controlled and reduce movement variability which increases with fatigue.

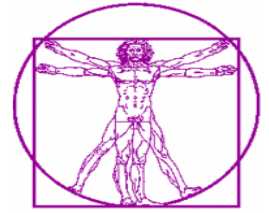
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PARTICIPANT 4



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For instance, if a player has a higher percentage of muscle activation in the triceps during the downswing of their shot, then this is the main muscle mover producing bat speed. Another player may have a higher percentage of muscle activation in the wrist flexors during the downswing of their shot meaning that this is the main muscle mover producing bat speed for them. Building an understanding of how each batter utilises their muscles allows a greater understanding of how a batter produces their bat speed leading to individual training programmes.

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Batting phases

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Muscle activation patterns

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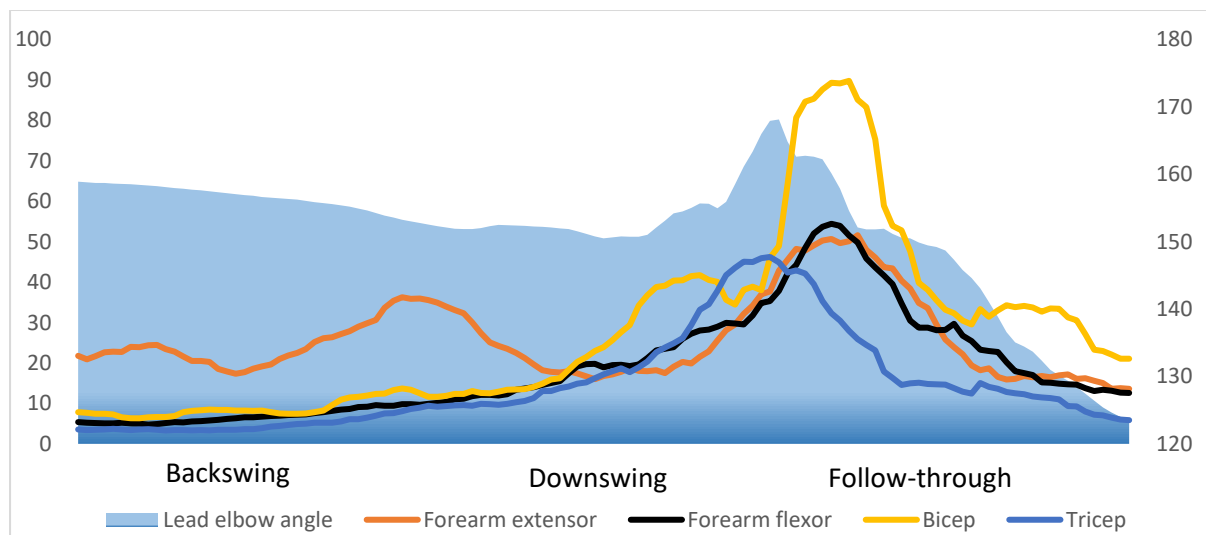


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 155° on the

right axis as the participant flexed/bent their arm in preparation to hit the ball. This then increases up to 168° as they extend/straighten their arm to peak at contact. The point where the blue shading and tricep (blue line) reach their peak is the moment of contact with the ball. This makes sense as the tricep is the main muscle used to extend/straighten the arm and this is found to be important for bat speed generation.

The lead-elbow angle does not change by a large margin in the shot and this is due to the participant having a Lateral bat backlift technique. Backlifts in cricket can be separated into two categories of techniques, the Lateral backlift technique and the Straight bat backlift technique (Noorbhai and Noakes, 2016). The lateral backlift is where the bat is angled further than the conventional 25° from the centre of the pitch whereas a straight backlift with the bat in line with the wicketkeeper (Stuelcken, Portus and Mason, 2005; Noorbhai and Noakes, 2016).

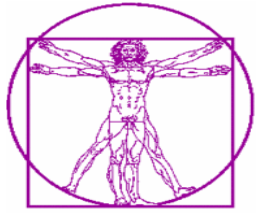
This means that you likely generate the majority of your bat speed by rotating your upper torso about your pelvis, this can be supplemented by a greater difference in elbow extension and wrist uncocking. Greater elbow extension would entail bending your lead elbow by a slightly greater amount and wrist uncocking would mean lifting the bat with your lead wrist and flexing it down into contact.

You have moderate activation in all muscles with the forearm extensor having greater activation in the backlift likely to some cocking of the wrist. Focusing on increasing the explosive power of your tricep which increases in activation rapidly during downswing and core power for rotation may help in generating bat speed. This must be balanced with fatigue resistance of the forearm extensors to keep your technique controlled and reduce movement variability which increases with fatigue.

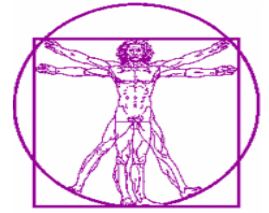
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For instance, if a player has a higher percentage of muscle activation in the triceps during the downswing of their shot, then this is the main muscle mover producing bat speed. Another player may have a higher percentage of muscle activation in the wrist flexors during the downswing of their shot meaning that this is the main muscle mover producing bat speed for them. Building an understanding of how each batter utilises their muscles allows a greater understanding of how a batter produces their bat speed leading to individual training programmes.

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Muscle activation patterns

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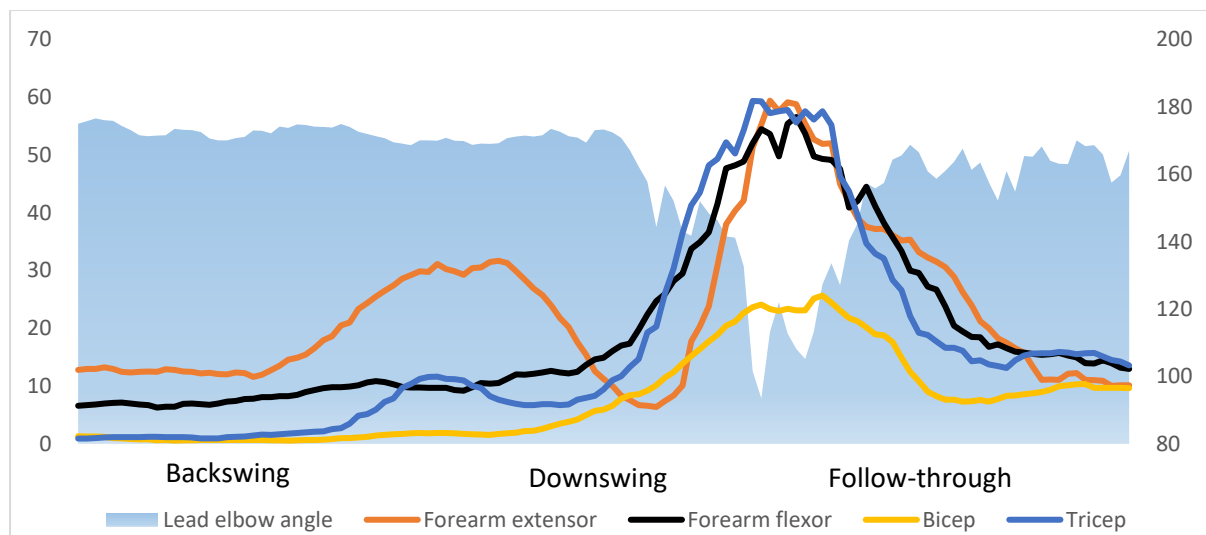


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 93° on the right

axis as the participant flexed/bent their arm in preparation to hit the ball. This then increases up to 121° as they extend/straighten their arm to peak at contact. The point where the blue shading rises and dips in the forearm flexor (black line) is the moment of contact with the ball. This makes sense as batters extend/straighten the arm at contact and this is found to be important for bat speed generation.

The tricep, forearm flexor and forearm extensor increase in activation leading up to contact. The tricep and forearm flexor result in movements linked to bat speed generation. The increase of the forearm extensor (orange line) in the backswing leading to the downswing may be due to lifting the wrist on the lead arm which is cocking of the wrist, lowering or uncocking this wrist in contact is linked to bat speed generation. This may be the reason for the high activation of the forearm art contact.

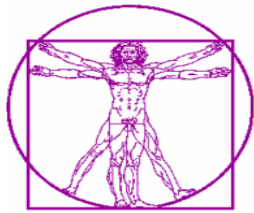
The reason the participant does not have a very flexed elbow in the shot is that they use a Lateral bat backlift technique. Backlifts in cricket can be separated into two categories of techniques, the Lateral backlift technique and the Straight bat backlift technique (Noorbhai and Noakes, 2016). The lateral backlift is where the bat is angled further than the conventional 25° from the centre of the pitch whereas a straight backlift with the bat in line with the wicketkeeper (Stuelcken, Portus and Mason, 2005; Noorbhai and Noakes, 2016).

This means that rather than extending the elbow you may rotate the upper torso about the pelvis to generate bat speed. Focusing on increasing the explosive power of your tricep which increases in activation rapidly during downswing and core power for rotation may help in generating bat speed. This must be balanced with fatigue resistance of the forearm extensors to keep your technique controlled and reduce movement variability which increases with fatigue. Also experimenting with extending the elbow more into contact may aid in bat speed generation.

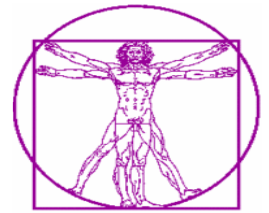
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PARTICIPANT 6



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Feedback from Arm Muscle Activation Study

Kinematic studies (measuring human motion) show key movements for generating bat speed in cricket batters to be elbow extension, wrist uncocking and the 'X-angle' (Peploe et al., 2019). Elbow extension is how flexed or straight the batter's lead arm (left arm for a right-handed batter) is during the shot. For example, if a batter straightens their arm more in a shot it has been found to generate more bat speed. Wrist uncocking (wrist flexion) is the movement of the wrist by lifting the hand up and down at the wrist joint when the forearm is stable. X-angle is torso rotation whereby, the more a batter rotates the shoulder and rib cage in comparison to their hips, the higher the bat speed generated (Peploe et al., 2019). Higher bat speed correlates to greater ball carry distance which is important for hitting boundaries (Taliep and Gray, 2010; Peploe et al., 2018).

This study aims to determine the patterns of muscle activation in the muscles moving elbow extension and wrist uncocking. The main muscle in elbow extension is located on the rear of the upper arm (triceps). The main muscle group involved in wrist uncocking is located on the underside of the lower arm (forearm flexors). In the body when a muscle activates to produce a movement it is termed the agonist, this then produces a reaction in the muscle on the opposite side of the limb which is termed the antagonist. The antagonist for the tricep is located on the front of the upper arm (bicep) and the antagonist for the forearm flexors is located on the top of the lower arm (forearm extensor).

Knowledge of the muscle activation of agonist and antagonist muscles is important to gain a greater understanding of the movement at the joint. For example, a study measuring the muscle strength of cricket batters found that batters with greater stability around the shoulder joint are more likely to have a higher batting average (Nunes and Coetzee, 2007). Muscle activation is measured using electromyography

which measures the electrical signal sent to the muscles from the brain (Basmaijian and DeLuca, 1985). What is important in this study is not the amount of muscle activation but the amount sent to each muscle at different points of the cricketing shot.

For instance, if a player has a higher percentage of muscle activation in the triceps during the downswing of their shot, then this is the main muscle mover producing bat speed. Another player may have a higher percentage of muscle activation in the wrist flexors during the downswing of their shot meaning that this is the main muscle mover producing bat speed for them. Building an understanding of how each batter utilises their muscles allows a greater understanding of how a batter produces their bat speed leading to individual training programmes.

The training programme can allow improved force production, leading to greater bat speed without disrupting the natural technique of the batter.

Batting phases

In cricket batting, the shot is divided into six phases: Stance and initial movement, backlift, stride, downswing, contact and follow-through (Peploe et al., 2018). The main phases of interest in this study are backlift, downswing, contact and follow-through. In the graphs below contact with the ball occurs at 0.8s, the time following which is follow through. Downswing is distinguished per shot and backlift is determined as the time before this.

Muscle activation patterns

Muscle activation of 0-30% is low, activation of 31-50% is moderate, 51-70% is moderately high and 71-100% is high. High activation means that the majority of the muscle fibres that are measured are active and producing a muscular force. Muscle activation cannot directly be compared to force so maximum activation does not mean maximum force but it does mean that the entire muscle is active. A higher activation in a movement means that the muscle has a high demand to produce that movement. The muscle that has a higher demand placed upon it should be the target of a strength and conditioning programme to better prepare it for the demands.

Forearm extensor

The forearm extensor muscles are involved in lifting the wrist upwards, ('cocking' the wrist) and in stabilising the wrist when impact is made with the ball. Cocking the wrist allows lifting the bat during the backswing and wrist stabilising helps keep the bat from twisting out of the hand when it hits the ball.

Forearm flexor

These muscles are involved in pulling the wrist downwards, also known as 'uncocking' the wrist and in stabilising the wrist when impact is made with the ball. Uncocking the wrist leads to more bat speed as the bat is pushed forward towards the ball.

Bicep

The biceps flex the arm at the elbow, this helps lift the bat during backlift and stabilises the arm in the shot.

Tricep.

The tricep extends the arm at the elbow which increases bat speed as the bat is moved towards the ball.

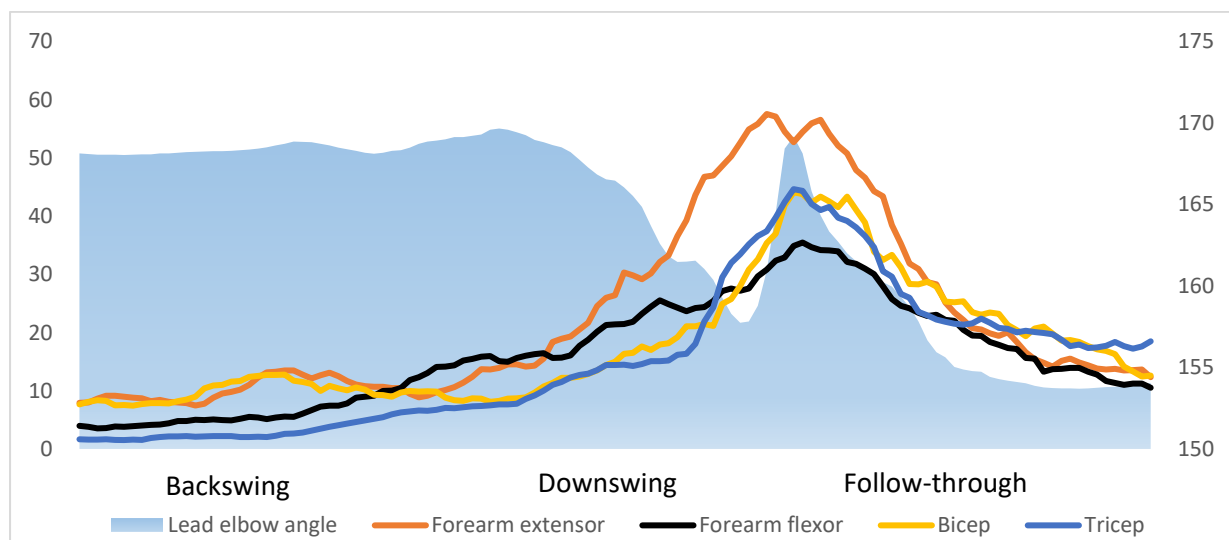


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 162° on the right axis as the participant flexed/bent their arm in preparation to hit the ball. This then increases up to 168° as they extend/straighten their arm to peak at contact. The point where the blue shading and tricep (blue line) reach their peak is the moment of contact with the ball. This makes sense as the tricep is the main muscle used to extend/straighten the arm and this is found to be important for bat speed generation.

The forearm extensor (orange line) has the highest amount of activation so fatigue resistance in this muscle is important. The forearm flexor (black line) has a lower amount of activation and has a gentle peak at contact rather than a rapid rise as can be seen by the tricep. This may mean that the participant is lifting the lead wrist into the backswing and downswing but not lowering or uncocking the wrist rapidly into contact to generate bat speed. This may aid in control however for the generation of bat speed a greater amount of wrist uncocking may be needed.

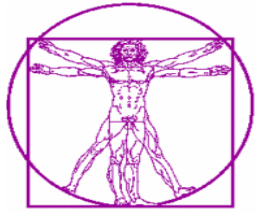
The reason for the lead elbow angle not having a great amount of change is that the participant uses a Lateral bat backlift technique. Backlifts in cricket can be separated into two categories of techniques, the Lateral backlift technique and the Straight bat backlift technique (Noorbhai and Noakes, 2016). The lateral backlift is where the bat is angled further than the conventional 25° from the centre of the pitch whereas a straight backlift with the bat in line with the wicketkeeper (Stuelcken, Portus and Mason, 2005; Noorbhai and Noakes, 2016).

This means that you may rotate your upper torso about your pelvis to generate bat speed rather than extending your elbow. Focusing on increasing the explosive power of your tricep which increases in activation rapidly during downswing and core power for rotation may help in generating bat speed. This must be balanced with fatigue resistance of the forearm extensors to keep your technique controlled and reduce movement variability which increases with fatigue. Experiment with a more flexed elbow and greater extension to generate bat speed.

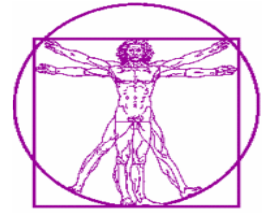
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Feedback from Arm Muscle Activation Study

Kinematic studies (measuring human motion) show key movements for generating bat speed in cricket batters to be elbow extension, wrist uncocking and the 'X-angle' (Peploe et al., 2019). Elbow extension is how flexed or straight the batter's lead arm (left arm for a right-handed batter) is during the shot. For example, if a batter straightens their arm more in a shot it has been found to generate more bat speed. Wrist uncocking (wrist flexion) is the movement of the wrist by lifting the hand up and down at the wrist joint when the forearm is stable. X-angle is torso rotation whereby, the more a batter rotates the shoulder and rib cage in comparison to their hips, the higher the bat speed generated (Peploe et al., 2019). Higher bat speed correlates to greater ball carry distance which is important for hitting boundaries (Taliep and Gray, 2010; Peploe et al., 2018).

This study aims to determine the patterns of muscle activation in the muscles moving elbow extension and wrist uncocking. The main muscle in elbow extension is located on the rear of the upper arm (triceps). The main muscle group involved in wrist uncocking is located on the underside of the lower arm (forearm flexors). In the body when a muscle activates to produce a movement it is termed the agonist, this then produces a reaction in the muscle on the opposite side of the limb which is termed the antagonist. The antagonist for the tricep is located on the front of the upper arm (bicep) and the antagonist for the forearm flexors is located on the top of the lower arm (forearm extensor).

Knowledge of the muscle activation of agonist and antagonist muscles is important to gain a greater understanding of the movement at the joint. For example, a study measuring the muscle strength of cricket batters found that batters with greater stability around the shoulder joint are more likely to have a higher batting average (Nunes and Coetzee, 2007). Muscle activation is measured using electromyography

which measures the electrical signal sent to the muscles from the brain (Basmaijian and DeLuca, 1985). What is important in this study is not the amount of muscle activation but the amount sent to each muscle at different points of the cricketing shot.

For instance, if a player has a higher percentage of muscle activation in the triceps during the downswing of their shot, then this is the main muscle mover producing bat speed. Another player may have a higher percentage of muscle activation in the wrist flexors during the downswing of their shot meaning that this is the main muscle mover producing bat speed for them. Building an understanding of how each batter utilises their muscles allows a greater understanding of how a batter produces their bat speed leading to individual training programmes.

The training programme can allow improved force production, leading to greater bat speed without disrupting the natural technique of the batter.

Batting phases

In cricket batting, the shot is divided into six phases: Stance and initial movement, backlift, stride, downswing, contact and follow-through (Peploe et al., 2018). The main phases of interest in this study are backlift, downswing, contact and follow-through. In the graphs below contact with the ball occurs at 0.8s, the time following which is follow through. Downswing is distinguished per shot and backlift is determined as the time before this.

Muscle activation patterns

Muscle activation of 0-30% is low, activation of 31-50% is moderate, 51-70% is moderately high and 71-100% is high. High activation means that the majority of the muscle fibres that are measured are active and producing a muscular force. Muscle activation cannot directly be compared to force so maximum activation does not mean maximum force but it does mean that the entire muscle is active. A higher activation in a movement means that the muscle has a high demand to produce that movement. The muscle that has a higher demand placed upon it should be the target of a strength and conditioning programme to better prepare it for the demands.

Forearm extensor

The forearm extensor muscles are involved in lifting the wrist upwards, ('cocking' the wrist) and in stabilising the wrist when impact is made with the ball. Cocking the wrist allows lifting the bat during the backswing and wrist stabilising helps keep the bat from twisting out of the hand when it hits the ball.

Forearm flexor

These muscles are involved in pulling the wrist downwards, also known as 'uncocking' the wrist and in stabilising the wrist when impact is made with the ball. Uncocking the wrist leads to more bat speed as the bat is pushed forward towards the ball.

Bicep

The biceps flex the arm at the elbow, this helps lift the bat during backlift and stabilises the arm in the shot.

Tricep.

The tricep extends the arm at the elbow which increases bat speed as the bat is moved towards the ball.

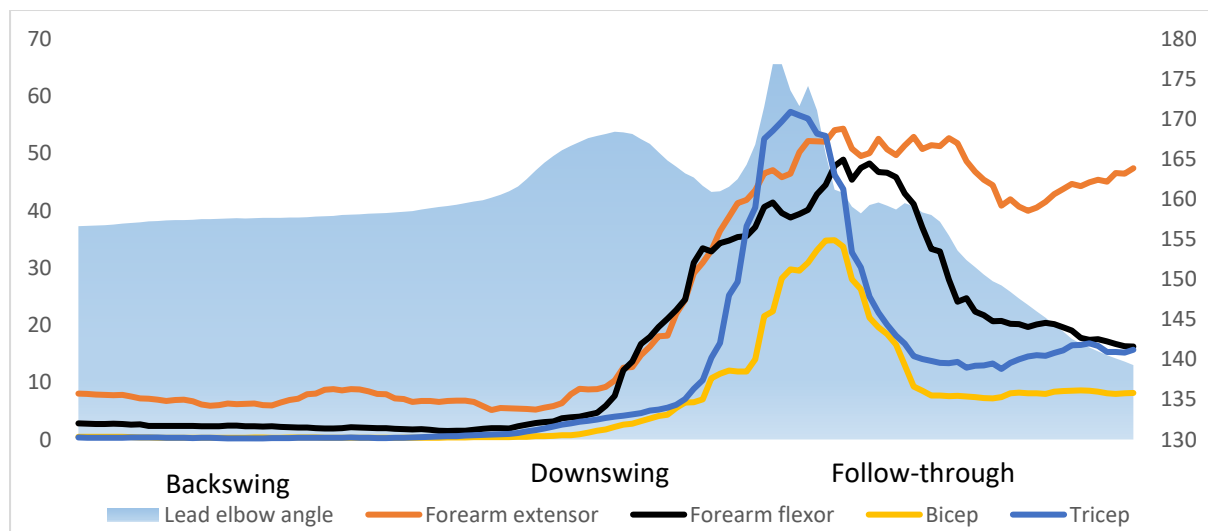


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 157° on the right axis as the participant flexed/bent their arm in preparation to hit the ball. This then

increases up to 178° as they extend/straighten their arm to peak at contact. The point where the blue shading and tricep (blue line) reach their peak is the moment of contact with the ball. This makes sense as the tricep is the main muscle used to extend/straighten the arm and this is found to be important for bat speed generation.

The forearm extensor (orange line) has a high amount of activation in the downswing and follow-through. This is due to lifting the lead wrist in the backlift to cock the wrist which can then be uncocked or flexed at contact to generate bat speed and resist the bottom hand to gain control of the bat in follow-through. Due to the high activation of this and the forearm flexor (black line) fatigue resistance in the forearms is important.

The reason the lead elbow is not very flexed before contact is that the participant uses a Lateral bat backlift batting technique. Backlifts in cricket can be separated into two categories of techniques, the Lateral backlift technique and the Straight bat backlift technique (Noorbhai and Noakes, 2016). The lateral backlift is where the bat is angled further than the conventional 25° from the centre of the pitch whereas a straight backlift with the bat in line with the wicketkeeper (Stuelcken, Portus and Mason, 2005; Noorbhai and Noakes, 2016).

This means that you likely generate bat speed by rotating your upper torso about your pelvis. Focusing on increasing the explosive power of your tricep which increases in activation rapidly during downswing and core power for rotation may help in generating bat speed. This must be balanced with fatigue resistance of the forearm extensors to keep your technique controlled and reduce movement variability which increases with fatigue. Experiment with bending your elbow more in the downswing to generate more bat speed.

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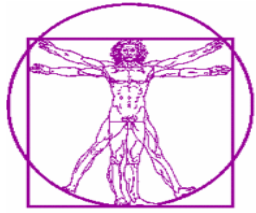
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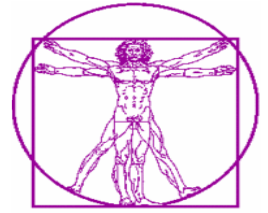
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Feedback from Arm Muscle Activation Study

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which measures the electrical signal sent to the muscles from the brain (Basmaijian and DeLuca, 1985). What is important in this study is not the amount of muscle activation but the amount sent to each muscle at different points of the cricketing shot.

For instance, if a player has a higher percentage of muscle activation in the triceps during the downswing of their shot, then this is the main muscle mover producing bat speed. Another player may have a higher percentage of muscle activation in the wrist flexors during the downswing of their shot meaning that this is the main muscle mover producing bat speed for them. Building an understanding of how each batter utilises their muscles allows a greater understanding of how a batter produces their bat speed leading to individual training programmes.

The training programme can allow improved force production, leading to greater bat speed without disrupting the natural technique of the batter.

Batting phases

In cricket batting, the shot is divided into six phases: Stance and initial movement, backlift, stride, downswing, contact and follow-through (Peploe et al., 2018). The main phases of interest in this study are backlift, downswing, contact and follow-through. In the graphs below contact with the ball occurs at 0.8s, the time following which is follow through. Downswing is distinguished per shot and backlift is determined as the time before this.

Muscle activation patterns

Muscle activation of 0-30% is low, activation of 31-50% is moderate, 51-70% is moderately high and 71-100% is high. High activation means that the majority of the muscle fibres that are measured are active and producing a muscular force. Muscle activation cannot directly be compared to force so maximum activation does not mean maximum force but it does mean that the entire muscle is active. A higher activation in a movement means that the muscle has a high demand to produce that movement. The muscle that has a higher demand placed upon it should be the target of a strength and conditioning programme to better prepare it for the demands.

Forearm extensor

The forearm extensor muscles are involved in lifting the wrist upwards, ('cocking' the wrist) and in stabilising the wrist when impact is made with the ball. Cocking the wrist allows lifting the bat during the backswing and wrist stabilising helps keep the bat from twisting out of the hand when it hits the ball.

Forearm flexor

These muscles are involved in pulling the wrist downwards, also known as 'uncocking' the wrist and in stabilising the wrist when impact is made with the ball. Uncocking the wrist leads to more bat speed as the bat is pushed forward towards the ball.

Bicep

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Tricep.

The tricep extends the arm at the elbow which increases bat speed as the bat is moved towards the ball.

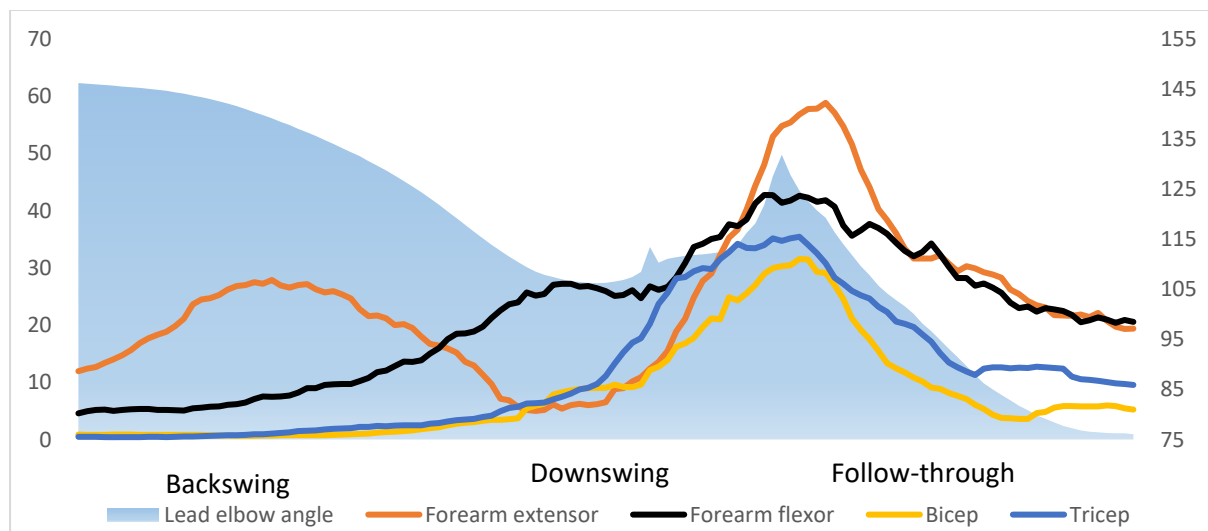


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 105° on the right axis as the participant flexed/bent their arm in preparation to hit the ball. This then

increases up to 131° as they extend/straighten their arm to peak at contact. The point where the blue shading and tricep (blue line) reach their peak is the moment of contact with the ball. This makes sense as the tricep is the main muscle used to extend/straighten the arm and this is found to be important for bat speed generation.

The reason that the lead elbow angle is very flexed and does not extend greatly is that the participant uses a Lateral bat backlift technique. Backlifts in cricket can be separated into two categories of techniques, the Lateral backlift technique and the Straight bat backlift technique (Noorbhai and Noakes, 2016). The lateral backlift is where the bat is angled further than the conventional 25° from the centre of the pitch whereas a straight backlift with the bat in line with the wicketkeeper (Stuelcken, Portus and Mason, 2005; Noorbhai and Noakes, 2016).

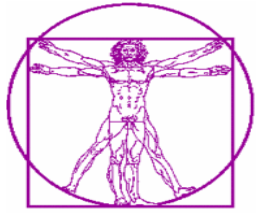
This means that the participant rotates the upper torso about the pelvis to generate bat speed. By extending the elbow more into contact more bat speed can be generated and the tricep can be used more. The forearm extensor (orange line) has a high amount of activation in the downswing and follow-through. This is due to lifting the lead wrist in the backlift to cock the wrist which can then be uncocked or flexed at contact to generate bat speed and resist the bottom hand to gain control of the bat in follow-through. Due to the high activation of this and the forearm flexor (black line) fatigue resistance in the forearms is important.

Focusing on increasing the explosive power of your tricep which increases in activation rapidly during downswing and core power for rotation may help in generating bat speed. This must be balanced with fatigue resistance of the forearm extensors to keep your technique controlled and reduce movement variability which increases with fatigue. Experiment with extending your elbow more in the downswing to generate more bat speed.

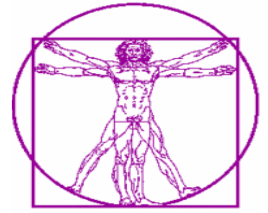
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PARTICIPANT 9



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This study aims to determine the patterns of muscle activation in the muscles moving elbow extension and wrist uncocking. The main muscle in elbow extension is located on the rear of the upper arm (triceps). The main muscle group involved in wrist uncocking is located on the underside of the lower arm (forearm flexors). In the body when a muscle activates to produce a movement it is termed the agonist, this then produces a reaction in the muscle on the opposite side of the limb which is termed the antagonist. The antagonist for the tricep is located on the front of the upper arm (bicep) and the antagonist for the forearm flexors is located on the top of the lower arm (forearm extensor).

Knowledge of the muscle activation of agonist and antagonist muscles is important to gain a greater understanding of the movement at the joint. For example, a study measuring the muscle strength of cricket batters found that batters with greater stability around the shoulder joint are more likely to have a higher batting average (Nunes and Coetzee, 2007). Muscle activation is measured using electromyography

which measures the electrical signal sent to the muscles from the brain (Basmaijian and DeLuca, 1985). What is important in this study is not the amount of muscle activation but the amount sent to each muscle at different points of the cricketing shot.

For instance, if a player has a higher percentage of muscle activation in the triceps during the downswing of their shot, then this is the main muscle mover producing bat speed. Another player may have a higher percentage of muscle activation in the wrist flexors during the downswing of their shot meaning that this is the main muscle mover producing bat speed for them. Building an understanding of how each batter utilises their muscles allows a greater understanding of how a batter produces their bat speed leading to individual training programmes.

The training programme can allow improved force production, leading to greater bat speed without disrupting the natural technique of the batter.

Batting phases

In cricket batting, the shot is divided into six phases: Stance and initial movement, backlift, stride, downswing, contact and follow-through (Peploe et al., 2018). The main phases of interest in this study are backlift, downswing, contact and follow-through. In the graphs below contact with the ball occurs at 0.8s, the time following which is follow through. Downswing is distinguished per shot and backlift is determined as the time before this.

Muscle activation patterns

Muscle activation of 0-30% is low, activation of 31-50% is moderate, 51-70% is moderately high and 71-100% is high. High activation means that the majority of the muscle fibres that are measured are active and producing a muscular force. Muscle activation cannot directly be compared to force so maximum activation does not mean maximum force but it does mean that the entire muscle is active. A higher activation in a movement means that the muscle has a high demand to produce that movement. The muscle that has a higher demand placed upon it should be the target of a strength and conditioning programme to better prepare it for the demands.

Forearm extensor

The forearm extensor muscles are involved in lifting the wrist upwards, ('cocking' the wrist) and in stabilising the wrist when impact is made with the ball. Cocking the wrist allows lifting the bat during the backswing and wrist stabilising helps keep the bat from twisting out of the hand when it hits the ball.

Forearm flexor

These muscles are involved in pulling the wrist downwards, also known as 'uncocking' the wrist and in stabilising the wrist when impact is made with the ball. Uncocking the wrist leads to more bat speed as the bat is pushed forward towards the ball.

Bicep

The biceps flex the arm at the elbow, this helps lift the bat during backlift and stabilises the arm in the shot.

Tricep.

The tricep extends the arm at the elbow which increases bat speed as the bat is moved towards the ball.

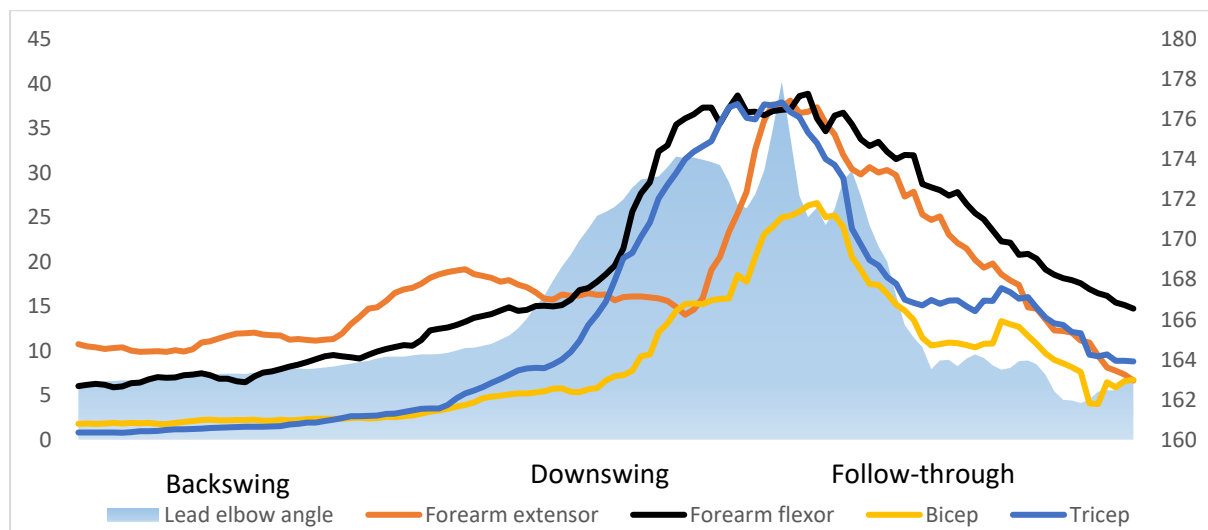


Figure 1: Average activation of muscles throughout the batting phases across all shots

The blue shaded area above represents the average angle of the lead elbow throughout testing. At the point of downswing, it can be seen to drop to 171° on the right axis as the participant flexed/bent their arm in preparation to hit the ball. This then increases up to 178° as they extend/straighten their arm to peak at contact. The point

where the blue shading and tricep (blue line) reach their peak is the moment of contact with the ball. This makes sense as the tricep is the main muscle used to extend/straighten the arm and this is found to be important for bat speed generation.

The reason that the lead elbow angle is not very flexed and does not extend greatly is that the participant uses a Lateral bat backlift technique. Backlifts in cricket can be separated into two categories of techniques, the Lateral backlift technique and the Straight bat backlift technique (Noorbhai and Noakes,2016). The lateral backlift is where the bat is angled further than the conventional 25° from the centre of the pitch whereas a straight backlift with the bat in line with the wicketkeeper (Stuelcken, Portus and Mason, 2005; Noorbhai and Noakes, 2016).

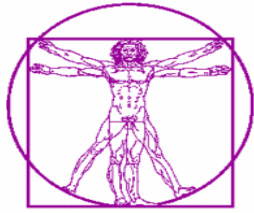
This means that the participant rotates the upper torso about the pelvis to generate bat speed. By flexing the elbow more in the downswing and extending the elbow more into contact more bat speed can be generated and the tricep can be used more. The forearm extensor (orange line) has a high amount of activation in the downswing and follow-through. This is due to lifting the lead wrist in the backlift to cock the wrist which can then be uncocked or flexed at contact to generate bat speed and resist the bottom hand to gain control of the bat in follow-through. Due to the high activation of this and the forearm flexor (black line) fatigue resistance in the forearms is important.

Focusing on increasing the explosive power of your tricep which increases in activation rapidly during downswing and core power for rotation may help in generating bat speed. This must be balanced with fatigue resistance of the forearm extensors to keep your technique controlled and reduce movement variability which increases with fatigue. Experiment with flexing your elbow more in the downswing to generate more bat speed.

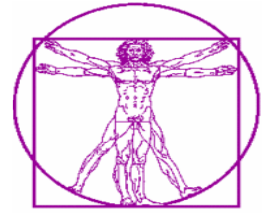
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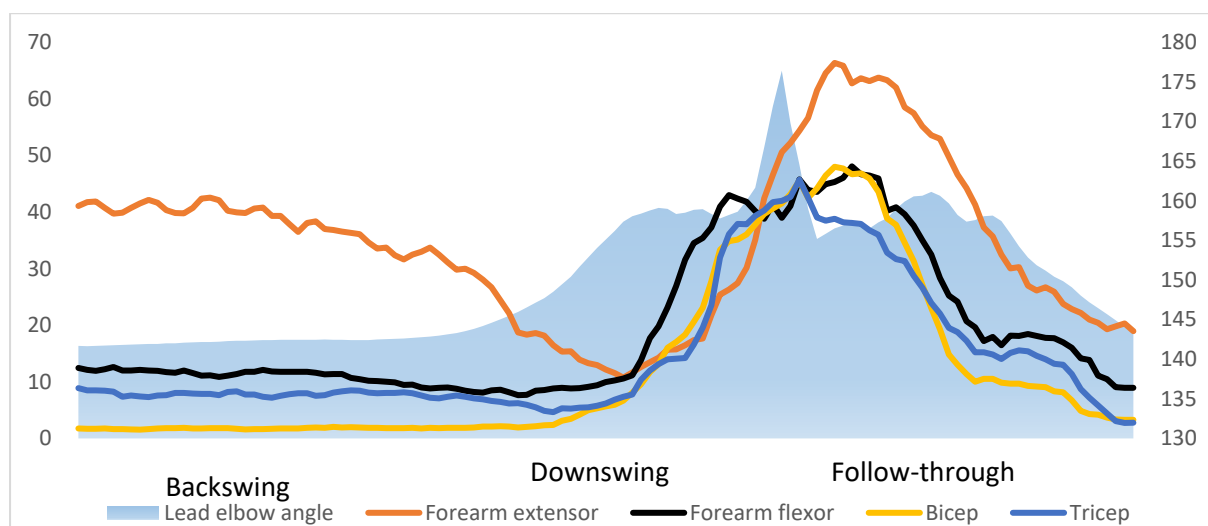


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References

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APPENDIX 3

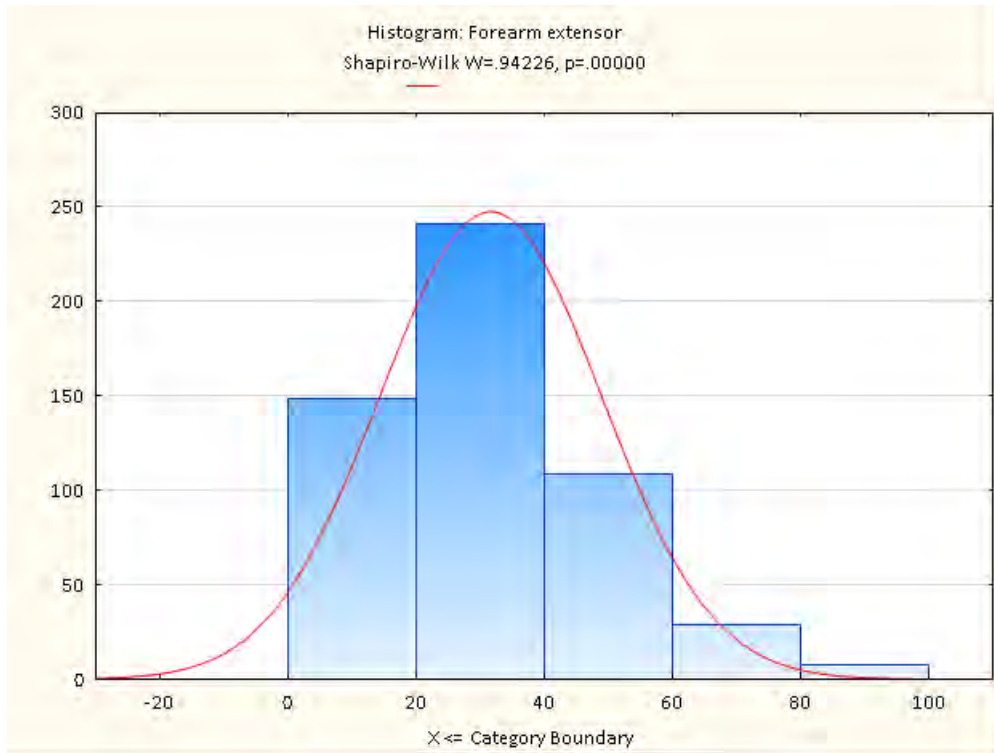
Distance hitting protocol (Peploe et al., 2019).

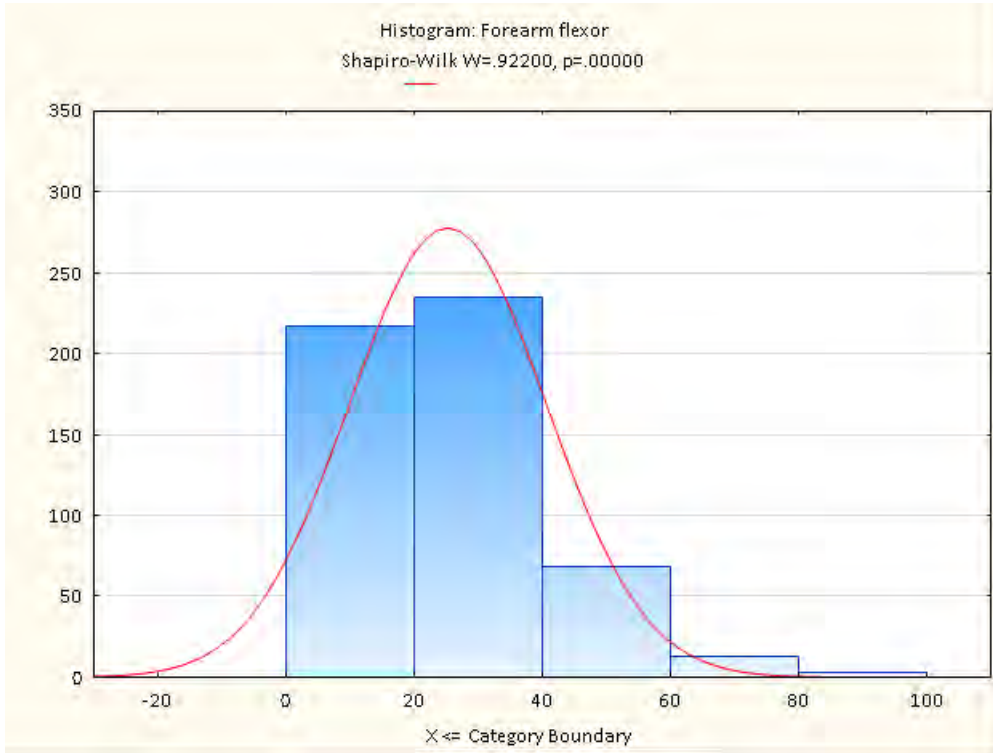
“2.1. Data collection

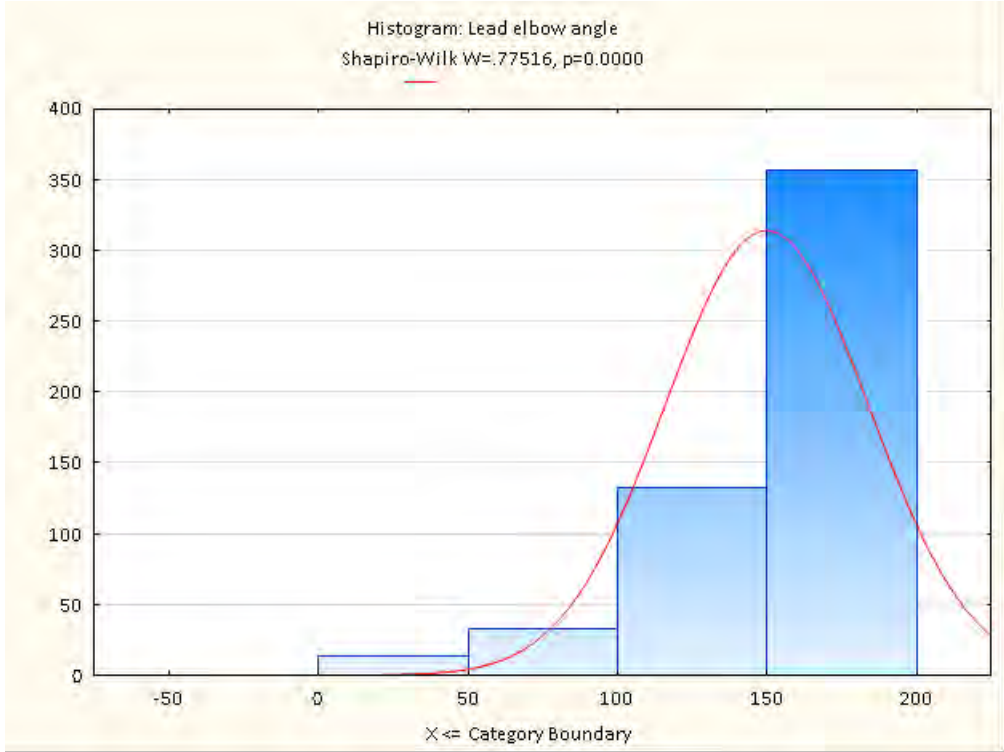
Twenty male cricket batsmen (22.5 ± 3.1 years, 1.82 ± 0.04 m, 80.0 ± 7.8 kg) participated in this investigation. Participants with large variation in range hitting experience and ability were selected so as to ensure a range of performances and not to distort the importance of individual variables. Participants included three international batsmen (England / England Lions), nine county batsmen including six who had represented England Under 19's, five Premiership club batsmen, and three club batsmen. Forty-six 14 mm retro-reflective markers were attached to each batsman (Fig. 1), positioned over or on padding adjacent to bony landmarks. An additional five markers were positioned on the bat (Fig. 1), as well as five 15×15 mm patches of 3 M Scotch-Lite reflective tape placed on the ball (Fig. 2). Each participant performed a series of shots (14 ± 4) against a bowling machine (BOLA Professional; release speed 32.3 ms^{-1}), aiming to hit the ball for maximum carry distance straight back over the bowling machine in the same manner that they would attempt in a match, and thus standardising the shots played by each participant. The bowling machine was directed towards a full length suitable for the shot. Resultant inbound ball speed on the approach to impact (after ball bounce) was $25.0 \pm 1.3 \text{ ms}^{-1}$. Each participant used their own bat throughout the data collection. This ensured familiarity for the participants, as the altered inertial properties of a standardised bat would have affected the kinematics of the shot. Previous work has shown little difference in batted ball speed for a given impact location, or impact location-ball speed relationship between different bats (Symes, 2006; Peploe et al., 2018). Only trials where the ball was projected forwards in the anterior-posterior direction (towards the bowling machine) postimpact were selected for analysis ($n = 239$; 12 ± 2 trials per participant).”

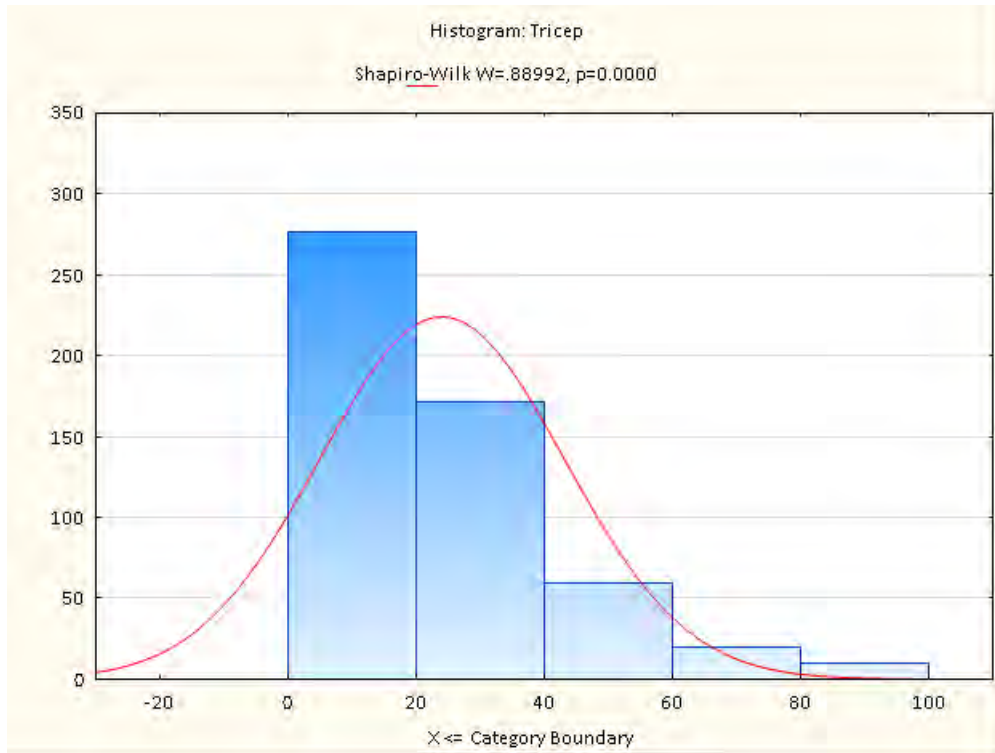
APPENDIX 4

STATISTICAL RESULTS









Depend.: Bicep	Kruskal-Wallis ANOVA by Ranks; Bicep (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =73.29761 p =.0000			
	Code	Valid N	Sum of Ranks	Mean Rank
P1	101	60	21059.00	350.9833
P2	102	48	16317.00	339.9375
P3	103	52	11798.00	226.8846
P4	104	60	13576.00	226.2667
P5	105	48	12073.00	251.5208
P6	106	36	13169.00	365.8056
P7	107	40	8168.00	204.2000
P8	108	64	15268.00	238.5625
P9	109	72	15186.00	210.9167
P10	110	56	17302.00	308.9643

Depend.: Forearm extensor	Kruskal-Wallis ANOVA by Ranks; Forearm extensor (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =31.60460 p =.0002			
	Code	Valid N	Sum of Ranks	Mean Rank
P1	101	60	17766.00	296.1000
P2	102	48	11398.00	237.4583
P3	103	52	15292.00	294.0769
P4	104	60	17373.00	289.5500
P5	105	48	13177.00	274.5208
P6	106	36	10306.00	286.2778
P7	107	40	11082.00	277.0500
P8	108	64	16954.00	264.9063
P9	109	72	13323.00	185.0417
P10	110	56	17245.00	307.9464

		Kruskal-Wallis ANOVA by Ranks; Forearm flexor (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =65.51791 p =.0000		
Depend.: Forearm flexor	Code	Valid N	Sum of Ranks	Mean Rank
P1	101	60	16694.00	278.2333
P2	102	48	13406.00	279.2917
P3	103	52	13079.00	251.5192
P4	104	60	7896.00	131.6000
P5	105	48	14492.00	301.9167
P6	106	36	9521.00	264.4722
P7	107	40	10938.00	273.4500
P8	108	64	21676.00	338.6875
P9	109	72	21234.00	294.9167
P10	110	56	14980.00	267.5000

		Kruskal-Wallis ANOVA by Ranks; Lead elbow angle (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =154.5394 p =0.000		
Depend.: Lead elbow angle	Code	Valid N	Sum of Ranks	Mean Rank
P1	101	60	14114.00	235.2333
P2	102	48	16300.00	339.5833
P3	103	52	14892.50	286.3942
P4	104	60	15349.50	255.8250
P5	105	48	10885.50	226.7813
P6	106	36	11600.50	322.2361
P7	107	40	12681.50	317.0375
P8	108	64	5390.50	84.2266
P9	109	72	27445.00	381.1806
P10	110	56	15257.00	272.4464

Kruskal-Wallis ANOVA by Ranks; Tricep (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =24.58512 p =.0035				
Depend.: Tricep	Code	Valid N	Sum of Ranks	Mean Rank
P1	101	60	17381.00	289.6833
P2	102	48	13074.00	272.3750
P3	103	52	10370.00	199.4231
P4	104	60	17569.00	292.8167
P5	105	48	15820.00	329.5833
P6	106	36	10877.00	302.1389
P7	107	40	10008.00	250.2000
P8	108	64	15889.00	248.2656
P9	109	72	18224.00	253.1111
P10	110	56	14704.00	262.5714

Multiple Comparisons z' values; Lead elbow angle (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =154.5394 p =0.000						
Depend.: Lead elbow angle	P1 R:235.23	P2 R:339.58	P3 R:286.39	P4 R:255.82	P5 R:226.78	P6 R:322.24
P1		3.479348	1.743522	0.728238	0.281818	2.664682
P2	3.479348		1.715798	2.792759	3.568156	0.508023
P3	1.743522	1.715798		1.041775	1.923022	1.067391
P4	0.728238	2.792759	1.041775		0.968407	2.034010
P5	0.281818	3.568156	1.923022	0.968407		2.795448
P6	2.664682	0.508023	1.067391	2.034010	2.795448	
P7	2.587630	0.679981	0.940793	1.936274	2.722122	0.146111
P8	5.425906	8.635153	6.991904	6.165796	4.820634	7.376608
P9	5.391031	1.441391	3.362977	4.630411	5.350110	1.864531
P10	1.293176	2.203842	0.467639	0.577604	1.499009	1.504914

Multiple Comparisons z' values; Lead elbow angle (Spreadsheet1) Independent (grouping) variable: Participant				
Depend.: Lead elbow angle	P7 R:317.04	P8 R:84.227	P9 R:381.18	P10 R:272.45
P1	2.587630	5.42591	5.39103	1.293176
P2	0.679981	8.63515	1.44139	2.203842
P3	0.940793	6.99190	3.36298	0.467639
P4	1.936274	6.16580	4.63041	0.577604
P5	2.722122	4.82063	5.35011	1.499009
P6	0.146111	7.37661	1.86453	1.504914
P7		7.45809	2.10019	1.390777
P8	7.458093		11.16084	6.641710
P9	2.100187	11.16084		3.940417
P10	1.390777	6.64171	3.94042	

		Multiple Comparisons z' values; Bicep (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =73.29761 p =.0000						
Depend.:		P1	P2	P3	P4	P5	P6	P7
Bicep		R:350.98	R:339.94	R:226.88	R:226.27	R:251.52	R:365.81	R:204.20
P1			0.368302	4.229185	4.410687	3.316384	0.453968	4.643051
P2	0.368302			3.646910	3.790133	2.796796	0.757560	4.093834
P3	4.229185	3.646910			0.021059	0.794726	4.137142	0.696451
P4	4.410687	3.790133	0.021059			0.842051	4.273735	0.698013
P5	3.316384	2.796796	0.794726	0.842051			3.346890	1.427193
P6	0.453968	0.757560	4.137142	4.273735	3.346890			4.542049
P7	4.643051	4.093834	0.696451	0.698013	1.427193	4.542049		
P8	4.039454	3.428101	0.403876	0.441808	0.438199	3.943632	1.100802	
P9	5.173814	4.470717	0.566536	0.567002	1.406980	4.899446	0.219919	
P10	1.460185	1.016729	2.751950	2.873788	1.885643	1.718052	3.267554	

		Multiple Comparisons z' values; Bicep (Spreadsheet1) Independent (grouping) variable:		
Depend.:		P8	P9	P10
Bicep		R:238.56	R:210.92	R:308.96
P1		4.039454	5.173814	1.460185
P2		3.428101	4.470717	1.016729
P3		0.403876	0.566536	2.751950
P4		0.441808	0.567002	2.873788
P5		0.438199	1.406980	1.885643
P6		3.943632	4.899446	1.718052
P7		1.100802	0.219919	3.267554
P8			1.039053	2.484266
P9		1.039053		3.553149
P10		2.484266	3.553149	

		Multiple Comparisons z' values; Forearm extensor (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =31.60460 p =.0002					
Depend.:		P1	P2	P3	P4	P5	P6
Forearm extensor		R:296.10	R:237.46	R:294.08	R:289.55	R:274.52	R:286.28
P1			1.955293	0.068945	0.231645	0.719515	0.300831
P2	1.955293			1.826427	1.736896	1.172361	1.429704
P3	0.068945	1.826427			0.154274	0.630849	0.232263
P4	0.231645	1.736896	0.154274			0.501118	0.100220
P5	0.719515	1.172361	0.630849	0.501118			0.344309
P6	0.300831	1.429704	0.232263	0.100220	0.344309		
P7	0.602590	1.194082	0.522751	0.395400	0.076279	0.259354	
P8	1.120840	0.928180	1.008858	0.885488	0.325127	0.662366	
P9	4.102297	1.816296	3.868522	3.860352	3.100554	3.202301	
P10	0.411670	2.313848	0.465014	0.639286	1.097231	0.654944	

		Multiple Comparisons z' values; Forearm extensor (Spreadsheet1) Independent (grouping) variable: Participant			
Depend.:		P7	P8	P9	P10
Forearm extensor		R:277.05	R:264.91	R:185.04	R:307.95
P1		0.602590	1.120840	4.102297	0.411670
P2		1.194082	0.928180	1.816296	2.313848
P3		0.522751	1.008858	3.868522	0.465014
P4		0.395400	0.885488	3.860352	0.639286
P5		0.076279	0.325127	3.100554	1.097231
P6		0.259354	0.662366	3.202301	0.654944
P7			0.389025	3.012558	0.963647
P8		0.389025		3.001664	1.518758
P9		3.012558	3.001664		4.453947
P10		0.963647	1.518758	4.453947	

		Multiple Comparisons z' values; Forearm flexor (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =65.51791 p =.0000						
Depend.:		P1	P2	P3	P4	P5	P6	P7
Forearm flexor		R:278.23	R:279.29	R:251.52	R:131.60	R:301.92	R:264.47	R:273.45
P1			0.035288	0.910395	5.185784	0.789675	0.421469	0.151306
P2		0.035288		0.895895	4.924492	0.715674	0.433996	0.176184
P3		0.910395	0.895895		4.086751	1.625743	0.385747	0.673306
P4		5.185784	4.924492	4.086751		5.678879	4.069551	4.487000
P5		0.789675	0.715674	1.625743	5.678879		1.096581	0.858553
P6		0.421469	0.433996	0.385747	4.069551	1.096581		0.252327
P7		0.151306	0.176184	0.673306	4.487000	0.858553	0.252327	
P8		2.172211	2.008532	3.014687	7.440973	1.243444	2.300147	2.089882
P9		0.616253	0.541424	1.539722	6.032627	0.242558	0.963019	0.702867
P10		0.372989	0.387074	0.535800	4.722600	1.129764	0.091516	0.185578

		Multiple Comparisons z' values; Forearm flexor (Spreadsheet1) Independent (grouping) variable:		
Depend.:		P8	P9	P10
Forearm flexor		R:338.69	R:294.92	R:267.50
P1		2.172211	0.616253	0.372989
P2		2.008532	0.541424	0.387074
P3		3.014687	1.539722	0.535800
P4		7.440973	6.032627	4.722600
P5		1.243444	0.242558	1.129764
P6		2.300147	0.963019	0.091516
P7		2.089882	0.702867	0.185578
P8			1.645101	2.511992
P9		1.645101		0.993553
P10		2.511992	0.993553	

Multiple Comparisons z' values; Tricep (Spreadsheet1) Independent (grouping) variable: Participant Kruskal-Wallis test: H (9, N= 536) =24.58512 p =.0035							
Depend.:	P1	P2	P3	P4	P5	P6	P7
Tricep	R:289.68	R:272.38	R:199.42	R:292.82	R:329.58	R:302.14	R:250.20
P1		0.577113	3.075997	0.110812	1.330388	0.381483	1.248937
P2	0.577113		2.353315	0.681588	1.809614	0.871652	0.668797
P3	3.075997	2.353315		3.182779	4.198767	3.058933	1.558925
P4	0.110812	0.681588	3.182779		1.225913	0.285517	1.348051
P5	1.330388	1.809614	4.198767	1.225913		0.803726	2.394196
P6	0.381483	0.871652	3.058933	0.285517	0.803726		1.459783
P7	1.248937	0.668797	1.558925	1.348051	2.394196	1.459783	
P8	1.488202	0.815283	1.689204	1.600788	2.749842	1.669689	0.061968
P9	1.350913	0.667515	1.904828	1.466653	2.649848	1.550847	0.095316
P10	0.942154	0.321813	2.117225	1.051039	2.199738	1.195943	0.385860

Multiple Comparisons z' values; Tricep (Spreadsheet1) Independent (grouping) variable:			
Depend.:	P8	P9	P10
Tricep	R:248.27	R:253.11	R:262.57
P1	1.488202	1.350913	0.942154
P2	0.815283	0.667515	0.321813
P3	1.689204	1.904828	2.117225
P4	1.600788	1.466653	1.051039
P5	2.749842	2.649848	2.199738
P6	1.669689	1.550847	1.195943
P7	0.061968	0.095316	0.385860
P8		0.182115	0.504809
P9	0.182115		0.342833
P10	0.504809	0.342833	

Kruskal-Wallis ANOVA by Ranks; Lead elbow angle (Spreadsheet1) Independent (grouping) variable: Shot type Kruskal-Wallis test: H (5, N= 516)				
Depend.:	Code	Valid N	Sum of Ranks	Mean Rank
Lead elbow angle				
1	1	128	33475.50	261.5273
2	2	60	16861.50	281.0250
3	3	148	37161.00	251.0878
4	4	80	20093.50	251.1688
5	5	48	12875.50	268.2396
6	6	52	12919.00	248.4423

Depend.: Tricep	Kruskal-Wallis ANOVA by Ranks; Tricep (Spreadsheet1) Independent (grouping) variable: Shot type Kruskal-Wallis test: H (5, N= 516)			
	Code	Valid N	Sum of Ranks	Mean Rank
1	1	128	34451.50	269.1523
2	2	60	15381.50	256.3583
3	3	148	38923.00	262.9932
4	4	80	19671.50	245.8938
5	5	48	11813.50	246.1146
6	6	52	13145.00	252.7885

Depend.: Bicep	Multiple Comparisons z' values; Bicep (Spreadsheet1) Independent (grouping) variable: Batting phase Kruskal-Wallis test: H (3, N= 536) =262.9601 p =0.000			
	1 R:89.530	2 R:297.43	3 R:381.90	4 R:305.14
1		10.98762	15.45240	11.39545
2	10.98762		4.46478	0.40783
3	15.45240	4.46478		4.05696
4	11.39545	0.40783	4.05696	

Depend.: Forearm extensor	Multiple Comparisons z' values; Forearm extensor (Spreadsheet1) Independent (grouping) variable: Batting phase Kruskal-Wallis test: H (3, N= 536) =195.0293 p =0.000			
	1 R:147.80	2 R:226.72	3 R:401.68	4 R:297.81
1		4.17094	13.41801	7.92814
2	4.17094		9.24707	3.75720
3	13.41801	9.247065		5.489866
4	7.92814	3.75720	5.48987	

Depend.: Forearm flexor	Multiple Comparisons z' values; Forearm flexor (Spreadsheet1) Independent (grouping) variable: Batting phase Kruskal-Wallis test: H (3, N= 536) =242.0781 p =0.000			
	1 R:98.478	2 R:306.26	3 R:380.74	4 R:288.52
1		10.98170	14.91797	10.04418
2	10.98170		3.93626	0.93753
3	14.91797	3.93626		4.87379
4	10.04418	0.93753	4.87379	

	Multiple Comparisons z' values; Tricep (Spreadsheet1) Independent (grouping) variable: Batting phase Kruskal-Wallis test: H (3, N= 536) =321.9226 p =0.000			
Depend.: Tricep	1 R:82.231	2 R:301.75	3 R:416.13	4 R:273.90
1		11.60172	17.64693	10.12977
2	11.60172		6.04520	1.47196
3	17.64693	6.04520		7.51716
4	10.12977	1.47196	7.51716	

	Multiple Comparisons z' values; Lead elbow angle (Spreadsheet1) Independent (grouping) variable: Batting phase Kruskal-Wallis test: H (3, N= 536) =21.51463 p =.0001			
Depend.: Lead elbow angle	1 R:289.87	2 R:228.31	3 R:306.20	4 R:249.62
1		3.253531	0.862783	2.127673
2	3.253531		4.116315	1.125858
3	0.862783	4.116315		2.990456
4	2.127673	1.125858	2.990456	