

19 Grip force dynamics in cricket batting

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Previous review articles of scientific research in cricket have focused upon biomechanics and injuries in fast bowling (see Bartlett *et al.*, 1996; Elliott *et al.*, 1996 and Elliott, 2000 respectively), cricket injuries in general (Finch *et al.*, 1999), and the physiological requirements of the game (Noakes and Durandt, 2000). Regarding batting in cricket, a recent review (i.e. Stretch *et al.*, 2000) has argued that all the sub-disciplines of sports science are necessary to understand the mechanisms underpinning skilled performance. Crucially, the affinity between the biomechanics of movement patterns and the underlying motor control mechanisms appears to be the most important factor in understanding effective stroke production, but one that has yet to be fully explored. The ecological approach to the study of processes of perception and action offers a viable platform for integrating motor control and biomechanics in the study of dynamic interceptive actions in sport. This notion clearly advocates the need for multidisciplinary or interdisciplinary research, as prioritised by Stretch *et al.* (2000).

Cricket batting is an example of a dynamic interceptive action, placed by Whiting (1969) in his second, most complex, category of ball skills – encompassing task constraints where a ball has to be received and sent away within the same movement. Batting in cricket requires players to select the most appropriate shot from a wide repertoire of attacking and defensive strokes against a variety of different bowlers – fast, spin, seam and swing. Successful interception of the cricket ball by the batsman¹ requires the cricket bat to be manoeuvred into the right place at the right time, so that the ball can be struck with the required force to send it in an appropriate direction (Savelsbergh and Bootsma, 1994). To achieve this goal, research described in many chapters of this text suggest that skilled batsmen require a combination of unobtrusive footwork, co-ordinated limb movements and precision gripping to deal effectively with the severe task constraints encountered when batting.

The grip is a key facet in successful batting as it is the only interface between the batsman and the cricket bat, through which all force and energy must be transmitted. The importance of precise control of grip forces can be illustrated in limited-overs cricket, where batsmen often have to improvise by ‘working’ the ball into gaps in the field. Additionally, skilled batsmen frequently manipulate grip firmness to play with ‘hard’ and ‘soft’ hands to control rebound velocity, particularly when surrounded by fielders in close catching positions, or when

playing on slow or fast pitches. Clearly, therefore, merely intercepting the ball by intersecting the flight path with the bat is not enough in competitive cricket. It would appear that variation in grip firmness is needed to place the ball strategically into gaps, in front of or behind fielders. Such a task requires the scaling of grip forces based on the use of visual information obtained from ball flight characteristics.

The purpose of this chapter is to provide an insight into the mechanisms underpinning skilled cricket batting, with the main emphasis on grip force dynamics. We begin by describing existing biomechanical investigations into this component of the cricket batting technique, highlighting the contributions and limitations of this line of research. We then discuss a theoretical account of cricket batting from an ecological approach in which we explore how batsmen manage visual search strategies and how visual information is used in modulation of grip force during stroke playing in competitive cricket. Theoretical understanding of the co-dependent relationship between perception and movement systems, outlined in the chapters by Montagne and Laurent, by Benguigui, Ripoll and Broderick, by Michaels and Zaal, and by Scott, along with considerations of biomechanical constraints, will be used to describe grip force dynamics before, during and immediately after bat–ball impact.

Biomechanical analysis of grip forces during batting

In Chapter 18 by Li and Turrell, the relationship between load force and grip force, in the task of striking a ball, was outlined. They reviewed the psychology literature on grip force and made the point that very few sport-related research programmes have been conducted into the ratio of load force and grip force during striking actions. One exception to this gap in the literature is the programme of work by Richard Stretch and colleagues in South Africa during the 1990s. They instigated the first scientific investigations into grip force dynamics in cricket batting. The main aim of that body of research was to verify empirically and evaluate the effectiveness of information outlined previously in pertinent coaching literature. Their results offered unequivocal support for the coaching literature, revealing that the top hand was indeed the most dominant hand during both the drive (D) and forward defensive (FD) strokes, with the bottom hand reinforcing at impact. Similar grip force patterns were evident during the initial part of both strokes, with greater forces applied by the top and bottom hands just before impact in the drive.

Manipulation of task constraints: effects of surface and bowling type

Data from their research programme suggest that task constraints such as pitch characteristics and bowling type seem to influence grip force dynamics during batting (Stretch, 1993; 1994). Stretch (1993) reported differences in the grip forces when batting on different surfaces and against different paced bowlers. Although results for the comparison of artificial and turf pitches and spin and medium-paced bowlers were collected from only two batsmen, both were experienced elite

cricketers. A purpose-built cricket bat equipped with pressure sensing transducers in the handle was used to measure top and bottom hand grip forces (see Figure 19.1).

Smaller forces were generated by the top hand when the batsmen played the drive against medium-paced bowlers on an artificial pitch compared to a turf pitch. In the drive, grip forces at impact of 195 N were recorded ($FD = 94$ N) with the peak force of 195 N reached 0.02 s post-impact ($FD = 102$ N at 0.04 s pre-impact). The force patterns for the bottom hand before and at impact were similar to those when batting on turf, while a relaxation and re-gripping of the bat during the follow-through was demonstrated when batting on the artificial pitch. The drive played on a turf pitch against a spin bowler demonstrated a peak force (158 N), which occurred 0.02 s post-impact for the top hand. A similar grip-force pattern was demonstrated for the bottom hand (peak force of 102 N at 0.02 s pre-impact), except that after impact a slight re-gripping of the bat occurred as the necessary hand forces were generated to regain control of the bat and to control the inertia of the bat during the follow-through. When playing the forward defensive, the peak forces for the bottom hand (58 N) occurred 0.08 s after impact (Stretch, 1993).

When playing the drive against a spin bowler on an artificial surface, the top hand demonstrated a similar, although smaller, grip-force pattern to when batting on turf, with the exception that the peak forces were reached 0.04 s post-impact (FD : peak force 74 N at 0.06 s post-impact). The grip-force pattern for the bottom hand showed similar, although smaller, forces than those for the top hand, with a relaxation and then re-gripping post-impact to control the bat during the follow-through. In the forward defensive, the bottom hand showed little change in grip forces throughout the stroke with a force at impact of 30 N, reaching a peak force of 34 N at 0.06 s post-impact (Stretch, 1993). Stretch *et al.* (2000) attributed the observed differences to the artificial pitch being faster than turf, with a more consistent and predictable bounce and with the ball not spinning or seaming as much as on turf.

How grip forces and load forces are coupled to the inertia and acceleration of the cricket bat during the backswing and downswing has yet to receive research attention, as does the analysis of the optimal range of grip forces. Stretch *et al.* (1995) measured maximal grip forces for both the top and bottom hands using a Takei grip dynamometer. These forces were 552 ± 75 N and 531 ± 74 N for the left and right hands respectively. The authors found no significant relationship between these maximum forces and the forces of the top and bottom hands exerted 0.02 s before impact. However, the mean forces, 0.02 s pre-impact of the top and bottom hands as a percentage of their maximum, were 36 ± 8 per cent (range 23–48 per cent) and 17 ± 8 per cent (range 5–32 per cent) respectively. These normalized values, particularly for the top hand, provide a good fit with the 24–48 per cent maximal voluntary contraction region suggested by Slifkin and Newell (2000) as providing the greatest flexibility for performers in scaling force to a force target in continuous isometric force production tasks. One may speculate that, on this basis, gripping the bat in this range may provide the required variability to enhance flexibility in tailoring force production to the specific task requirements and perturbations in the environment. Clearly, the application of these results from

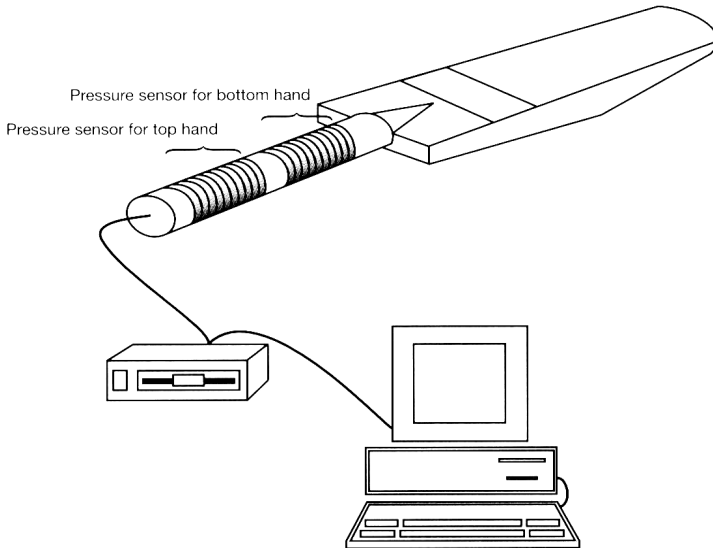


Figure 19.1 Diagram of the experimental bat showing the positions of the pressure sensors (adapted from Stretch *et al.* 1998, with permission).

experimental studies of isometric force production, to such a dynamic task as cricket batting, warrants further investigation.

Limitations of the work of Stretch and colleagues

Although the work of Stretch and colleagues has provided some preliminary insights into grip force dynamics during front foot stroke production, there are some apparent limitations associated with their research. Their work needs to be extended due to its descriptive nature and the use of limited sample and trial sizes in a cross-sectional approach, particularly in the investigations into the effects of different bowling types and surface conditions. Future research in this area should emphasise longitudinal designs, investigating the use of individual-specific grip force strategies for specific task constraints. The atheoretical nature of the research, particularly the lack of input from theories of motor control, is also a major limiting factor in the applicability of the existing research. In this chapter, and in Chapter 16 by Lees and Davids, an integrated approach is proposed for the study of dynamic interceptive actions. In Chapter 16, the emphasis is on integration of dynamical systems theory and biomechanics in an analysis of processes of movement co-ordination and control in soccer kicking. Later in this chapter, we argue that an ecological interpretation promises to provide a viable platform for integrating motor control and biomechanics in modelling of grip force dynamics in cricket batting. But first, in the following section, we review the implications of motor control research on grip force dynamics for understanding how cricketers may regulate grip force dynamics during batting.

Grip force dynamics at bat–ball impact: evidence from motor control research

The nature of grip force dynamics during bat–ball impacts requires clarification. This is a particularly important issue in the exploration of controlling reaction impulse and rebound velocity in the implementation of ‘hard’ versus ‘soft’ hands batting tactics, as previously discussed. The review of the grip force data produced by Stretch and colleagues revealed that peak grip force occurs before impact and reduces through the impact period in both the forward drive and defensive strokes. One may speculate that this feature facilitates the transfer of angular velocity to the cricket bat and thus is a mechanism for increasing its horizontal impact velocity. However, this is not necessary in the forward defensive stroke as the aim is often to play with a ‘dead’ bat, using solely the momentum of the ball. Additionally, the results revealed that the peak horizontal velocity of the cricket bat coincided with peak grip forces in both strokes. Similar findings have been found in other striking activities such as golf (Shibayama and Ebashi, 1983), softball (Messier and Owen, 1984) and baseball (Race, 1961; Breen, 1967; McIntyre and Pfautsch, 1982). The consensus is that the body segments slow down just before contact in preparation for the force of impact during these dynamic interceptive actions (Plagenhoef, 1971).

Contrasting evidence can be found in the motor control literature where a limited body of experimental research has been devoted to the regulation of grip forces when approaching a collision (e.g. see Chapter 18 by Li and Turrell; Turrell *et al.*, 1999) and the role of vision in the scaling of grip forces (e.g. Turrell, 2000). The chapter by Li and Turrell reviews how, using a novel laboratory experiment, Turrell *et al.* (1999) found fundamental differences between receiving and producing a collision. When receiving a collision, little change in grip force occurred before impact. The largest change in grip force occurred after impact. This is consistent with previous research (Johansson and Westling, 1988), which suggested this effect to be due to a late latency reflex to prevent slippage of the striking implement in the hand. When asked to produce a collision, however, the participants were able to increase grip forces at a lower rate of change, peaking at impact. The post-impact burst that occurred in the producing condition was very small or often not observed at all. Grip force was scaled to load force with a higher gain in the producing condition and predictions about forthcoming collisions were seemingly more accurate.

Li and Turrell’s suggestions, in Chapter 18, of a tight coupling between grip and load forces during the production of a collision needs to be substantiated under task constraints more closely related to cricket batting because their pendulum was stationary. Under these specific task constraints, direct collisions between the centre of percussion of the striking implement and the pendulum might result in minimal or no increase in load force during impact (Bartlett, 1997). As greater accuracy is inevitable during the producing condition, this task constraint might account for the lack of a burst of grip force post-impact. Conversely, inaccurate striking might simply cause the relatively high post-impact bursts in the receiving conditions rather than a lack of grip force scaling during the pre-impact phase.

The research outlined in the chapter by Li and Turrell provides some valuable insights from a motor control perspective for the analysis of grip force characteristics when intercepting the ball during attacking and defensive strokes in cricket, but similar research is required under more dynamic task constraints. The inter-relationship between the accuracy of bat–ball impact in relation to the centre of percussion of the bat, rebound velocity, recoil impulse and grip forces needs research attention to provide information about how cricketers of various skill levels can manipulate force and directional properties of impacts during batting.

Cricket batting: the role of biomechanics and the ecological approach

To date, the coalition of motor control and biomechanics in cricket research has yet to be realised, largely because of the tendency for the underlying control processes in cricket batting to be modelled from an information-processing standpoint (e.g. Abernethy, 1981; Abernethy and Russell, 1984; Penrose and Roach, 1995). In Chapter 16 by Lees and Davids argue that the emphasis of the ecological approach, on the co-ordination and control of degrees of freedom of the movement system in forming a perception–action coupling, presents a greater opportunity for the integration of biomechanics and motor control research. It certainly fits with the idea, raised and discussed in many chapters in this book, that movements can be continuously regulated by information to provide fine-grained adjustments in line with the changing demands of dynamic performance contexts (Savelsbergh and Bootsma, 1994; Bootsma *et al.*, 1997).

Information sources: identification and utilisation

In Chapter 1 it was argued that, although other perceptual mechanisms are at work (i.e. haptic, auditory, proprioceptive), much of the perceptual information used to regulate movement behaviour during cricket batting is provided by the visual system. Energy in the form of light reflected from important surfaces and objects, such as the ball and the fielders, creates an optic flow field that geometrically specifies the exact layout of the environment at any instance. The optic array contains veridical, or invariant, information sources such as motion parallax, texture density gradients and gradient of image size (Bruce *et al.*, 1996), which the perceptual system ‘resonates’ to, autonomously characterising them in terms of their possibility for action, or affordances (Williams *et al.*, 1992, 1999). The alliance between invariants and affordances means that a tight coupling exists between the state of the environment and system dynamics, allowing the batsman to regulate motor activity ‘on-line’ right up until the point of bat–ball impact.

In Chapters 1 and 7 of this book it has been outlined how, from an ecological perspective, a relevant property of the perceptual flow can act as information to steer, guide or regulate key movement parameters (e.g. force) throughout the course of the action. A lot of recent evidence was reviewed in support of the prospective

control strategy and one particular model, the required velocity model, has seen compelling empirical support. The required velocity model emphasises that the performer regulates the amount of acceleration of an implement such as a cricket bat, produced on the basis of the perceptually specified difference between the required velocity and the current velocity of the implement for interception. The implications of the required velocity model for cricket batting is that the instantaneous distance/velocity of a cricket ball approaching the hand–bat movement axis is divided into the distance a hand–bat system has to move sideways to reach the interception point. Research (e.g. Peper *et al.*, 1994; Montagne *et al.*, 1999; Montagne *et al.*, 2000) has supported the predictions of the required velocity model in the context of ball catching.

Eye movement studies

Results from a recent study of eye movement behaviour during cricket batting by Land and McLeod (2000) can also be interpreted as providing some evidence in support of the use of optical information sources for regulating batting. This study is discussed at some length in Chapter 1 of this book. To briefly re-iterate: using a head-mounted video camera operating at 50 Hz, Land and McLeod (2000) monitored the direction of gaze of three cricket batsmen of various expertise. The batsman's task was to execute attacking and defensive, front- and back-foot cricket strokes based on the line and length of medium-paced (25 m s^{-1}) deliveries produced by a bowling machine. The main findings of this study were that batsmen facing fast bowlers do not keep their eye on the ball throughout its flight and, despite their widely different skill levels, all three batsmen used similar eye movement strategies. The gaze of the fovea was initially focused on the point of delivery, remaining stationary for a period while the ball dropped into the field of view. A key observation discussed in Chapter 1 was that a saccade was then made to bring the focal point of the fovea below the ball, close to the point where the ball would subsequently bounce. All three batsmen tracked the ball for up to 200 ms after bouncing before both the eye and head moved rapidly down in an attempt to track the latter part of the ball's flight.

While the authors preferred to interpret these findings as evidence against the use of a perception–movement coupling to regulate the striking action, they did not rule out the existence of image expansion and changing binocular disparity as a viable means of refining time and position of contact during the post-bounce period. They were reluctant to accept it as the principal method for predicting time-to-contact, particularly during early ball flight. However, there are several good reasons for reconsidering the idea that optical information is not used throughout ball flight to regulate batting action.

Role of the image-retina system

First, it is possible that this eye movement strategy may simply reflect the severe task constraints of batting against fast bowling speeds. Although batsmen may not

look directly at the cricket ball throughout the period between release and ball pitching, this finding does not signify that visual information was not used during this period. The image of the cricket ball may have been allowed to wash across the retina until it reaches the bounce location. Although this strategy is less sensitive than focusing directly on the ball, it is probably sufficient to estimate the direction, length and speed of the delivery, providing enough information to direct footwork, select the appropriate stroke and give an approximation of the time and location of impending ball pitch. This would appear to be a more suitable mechanism for counteracting the severe spatio-temporal constraints of fast bowling where pursuit eye tracking would be impossible. Moreover, focusing on the cricket ball throughout early ball flight has been shown to be of limited benefit, since early retinal information about absolute distance and speed is considered to be unreliable (Regan, 1997).

Penrose *et al.* (1976) also demonstrated that the cricket ball decelerates between 4 and 9 ms⁻¹ from the period between ball release and arrival at the batting end. Such a marked deceleration, particularly during the pitching phase, would fit well with the use of a prospective control strategy (Montagne *et al.*, 1999; Montagne *et al.*, 2000). A far more tangible strategy for successfully intercepting a cricket ball would be to wait until the ball has bounced, using the subsequent unambiguous optical information to prospectively regulate stroke output parameters and impact conditions. This notion is substantiated by the postulation of short visual-motor delays in other ecological accounts of dynamic interceptive activities. For example, Lee *et al.* (1983) postulated visual-motor delays of 55–130 ms in a ball-striking task and Bootsma and van Wieringen (1990) demonstrated visual-motor delays of around 105–122 ms when modifying a forehand drive in table tennis. The use of a prospective control strategy would make timing considerably easier and sufficiently precise to satisfy the small timing windows postulated by Regan (1997) and McLeod (1987) for successful interception of the cricket ball during the hook (2.5 ms) and the leg glance (4 ms) strokes respectively.

Related to this issue is the question: how do eye movement and visual search strategies change with deliveries of different lengths? Land and McLeod (2000) revealed that the bounce length affected gaze movement in two ways. First, the delay before the early downward saccade increased as the ball bounced closer to the batsman and, secondly, the amount of smooth tracking that accompanied the initial saccade increased as the length of the delivery increased. This combination of saccade and smooth tracking allowed the gaze of the fovea to reach the bounce point accurately and well ahead of the ball (Land and McLeod, 2000). Moreover, for over-pitched deliveries, all three batsmen seemed to begin tracking before the ball bounced.

It would appear from these results that cricket batsman look for the most reliable information on which to guide batting actions. Where deliveries are pitched short, the cricket ball, having bounced, is unlikely to deviate laterally, change trajectory or decelerate considerably making pursuit tracking possible. Image expansion information during this extended post-bounce tracking period can then be used to regulate and refine batting mechanics, producing consistent impact conditions.

Over-pitched deliveries are also subject to extended tracking periods just before bouncing, where batsman can again use image expansion information. The decrease in ball speed due to air resistance will be small and predictable and, providing the batsman is positioned sufficiently close to the bounce location, the deceleration of the cricket ball due to interaction with the pitch will be nullified. Clearly, further research into the integration of eye and hand movements during cricket batting is needed to clarify how performers pick up and use information for guiding bat movements.

Support from studies of eye movements during manual aiming

A second source of support for the use of visual regulation strategies during cricket batting can be found in recent studies of manual aiming. Manual aiming is a type of interceptive action that is obviously more static than cricket batting. However, there are many similarities between the two types of interceptive action, especially when aiming is with a stylus. Perhaps the main difference is in the amount of movement of the target to be intercepted. Recent studies of rapid manual aiming movements have found that a two-component model (rapid initiation phase of the aiming movement towards the target followed by a homing-in phase) can explain eye and hand movements under these task constraints (e.g. Khan and Franks, 2000). We note how eye movements during manual aiming bear some resemblance to the eye movement strategies of cricketers identified by Land and McLeod (2000). In the manual aiming research, the role of vision in both phases of the movement was seen to increase error correction effectiveness in reaching the target. Essentially, it has been found that hand movements towards a target are initiated under visual control and followed by a visually based corrective phase as the limb approaches the target (e.g. Helsen *et al.*, 1998; Khan and Franks, 2000). The relevant point for this chapter is that eye movements during manual aiming show similar patterns of behaviour to hand movements. Eye movements are launched before hand movements and typically fall short of the target by around three degrees. After that it appears that micro-saccades are used to bring the eye over the target. Most importantly, the initial saccade appears to finish just when the limb reaches the point of peak acceleration, signifying that the movement system is able to use visual feedback in making small adaptive movements of the hand in locating the target. Interestingly, a significant correlation was found between the number of eye corrections and the number of corrective adaptations in joints of the aiming arm. In relation to the findings of Land and McLeod (2000), manual aiming research has found stable temporal associations for the initiation of second eye movements and the start of second finger movements as the target is approached (Khan and Franks, 2000). The implication, that there is ample time to seek and use visual information to control the initiation and homing in phases of rapid manual aiming movements, needs to be investigated in the context of cricket batting.

Functional variability of grip forces in cricket batting

We hypothesise that relatively small variability in low levels of intra-trial grip forces are apparent during the period between release and ball pitch. This is mainly because of a general organisation of the mechanical degrees of freedom of the more proximal segments of the kinetic chain during the early part of the bi-phasic batting action. Inter-trial variability is likely to be greater because of the different intentions of the batsman to play attacking or defensive strokes depending on the task context, or to play with 'hard' or 'soft' hands. Greater centripetal accelerations, generated by swinging the cricket bat faster, increase load forces. These changes must be counteracted by proportionally increasing the magnitude of grip force to avoid slipping.

Intra-trial grip force variability is likely to increase markedly during the post-bounce period where visual information may be used to modify the position of the bat on the basis of ongoing visual information from the approaching ball. Additionally, co-ordination of the more distal segments in the kinetic chain becomes increasingly more complex as the number of mechanical degrees of freedom increases (Bartlett, 1999). As the grip represents the terminal articulation in the upper body kinetic chain, movement discrepancies produced by preceding body segments must be accounted for and refined to produce accurate bat-ball impacts. In Chapter 1 it has already been noted from studies of national and international throwers that higher than expected levels of intra-individual variability have been reported (Bauer and Schöellhorn, 1997). Higher levels of variation were found within the performance clusters of international athletes, rejecting the idea of common optimal movement patterns, when the last 200 ms of javelin and discus throwing was measured. From these data, it might be concluded that any observed variability in skilled cricket batting is likely to be compensatory, particularly during the final phase of the movement, to allow a tight fit to develop between actor and environment (see also Bootsma and Van Wieringen, 1990). McLeod (1987) has previously raised the issue of the large inertia of the cricket bat, suggesting that it could prevent stroke adjustments during the last 180–200 ms of ball flight. However, if the cricket bat were already moving as the ball approached, the problems of inertia could be overcome to a large extent by exploiting existing momentum. Future analyses of grip forces will reveal whether the effector response allows adjustment, based on ongoing visual information, or whether resistance from inertia forces prevents any adjustment from occurring.

Finally, we hypothesise that inter-trial grip forces will vary quite considerably during the follow-through in relation to the momentum of the bat. Stretch *et al.* (1998) reported a slight increase in grip forces during the follow-through, which they attributed to regaining the control of the cricket bat after impact.

Implications for bowlers

Our interpretation of the use of visual information in cricket batting also has profound implications for tactical awareness of cricket bowlers wishing to make life difficult for batsmen. First, bowlers should try to bowl a length that is sufficiently far up the

pitch to exploit visual–motor latencies of only 80–100 ms quoted in the literature (e.g. Ballard *et al.*, 1998). By doing this, the time constraints will be severe enough to inhibit late modification of the batting action once the stroke has been initiated. Any deviation, such as the ball ‘seaming’ off the pitch, will not be easily picked up by the batsman, possibly resulting in the ball being deflected off the edge of the bat and being caught. Secondly, the bowler should also try to bowl ‘yorkers’ (full-length deliveries that pitch directly beneath the batsman in the area between the popping crease and the stumps). As batsmen find tracking the ball at the end of its trajectory difficult, the bowler should exploit this weakness by making the ball deviate late, possibly using reverse swing (see Barrett and Wood, 1996). Thirdly, the bowler should use strategies, such as holding the ball loosely or hyperextending the wrist at delivery, to vary bowling speed and flight along the same trajectory (Regan, 1997). Manipulating ball release in this way will make identifying the area and time of bounce tenuous, thus restricting the batsman’s capacity to adapt the grip and the spatial trajectory of the bat late in performance.

Summary and recommendations for future research

Throughout this chapter, we have promoted the grip on the bat handle as an important technical component of the batting action and discussed how precise control of grip force dynamics is an integral feature of skilled cricket batting. We have explored the biomechanical constraints imposed on grip force dynamics before, during and after bat–ball impact, highlighting the research work undertaken by Stretch and colleagues and Li and Turrell in describing the effects of manipulating task constraints on grip forces. Following on from this, we argued that the ecological approach is a relevant theoretical framework for understanding the processes involved in controlling grip forces. Gibson’s theory of ecological optics (Gibson, 1979) formed the foundation for our discussion of sources of perceptual information available for pick-up by the batsman and we re-evaluated Land and McLeod’s (2000) findings on visual search strategies in cricket batting. Our interpretation of their findings reaffirms the potential role of optic invariants, such as image expansion and rate of change of binocular disparity, as probable control mechanisms underpinning cricket batting. On this basis, we hypothesised a functional role for grip force variability, particularly during the latter stages of ball flight, claiming that it has an adaptive quality and that it is an integral component in satisfying task constraints of batting. We also predicted variations in magnitudes of grip forces between trials according to the intentions of the batsman to play either attacking or defensive strokes. Finally, tactical guidelines were postulated that bowlers might seek to exploit to dismiss a batsman. These implications are based on our interpretation of how batsmen pick up and use information sources and the limitations of the perceptual–motor system at adapting to task constraints and environmental perturbations.

We advocate that future research into cricket batting should be interdisciplinary in nature, integrating techniques and theory from biomechanics and motor control. Recommendations for specific avenues of future research have also been made

throughout this chapter. We suggest that identifying grip force strategies used by batsmen of different skill levels is a priority. Owing to the inherently large amount of variability predicted in the data, both longitudinal and cross-sectional research designs need to be incorporated to identify individual-specific grip force strategies as well as to generalise to different sub-populations.

Future research designs need to pay particular attention to the statistical methods used to evaluate the variability in force–time data. Traditional summary statistics, such as the within-subject standard deviation, only provide a global, time-discrete estimate of behaviour and neglect the characterisation of the trial-to-trial or moment-to-moment relations of events in performance time series (Newell and Corcos, 1993). The standard deviation only captures the *magnitude* of fluctuations in system output. However, variations in system output can be measured along another dimension independently of the magnitude. By analysing force–time data in the time domain using a time series analysis, the *structure* of system dynamics can be identified (Slifkin and Newell, 1999, 2000). Orderly relations of events in a time series analysis may be interpreted as a functional basis for variability instead of noise in the perceptual–motor system. Furthermore, as cricket batsmen aim to strike the cricket ball near the centre of percussion of the cricket bat (Page, 1978), we suggest that the location of bat–ball impact also needs to be evaluated in addition to the degree of orderliness. A measuring system similar to the one described by McKellar *et al.* (1998) needs to be incorporated to measure the precise location of bat–ball impact. Knowledge of the location of bat–ball impact in relation to the centre of percussion will also help to clarify how ‘off-centre’ collisions affect the control of grip force during the impact phase.

Technological developments in ball tracking devices, such as the Hawk-Eye system (Roke Manor Research, UK), hold great potential and promise to make valuable contributions to this line of research. Such devices are able to calculate the spin and the swerve of the cricket ball during the flight phase and predict future ball flight based on the lateral deviation and rebound characteristics of the pitching phase. Manufacturers claim that these devices can reliably measure the location of the cricket ball at any instant from ball release to bat–ball impact to within 5 mm of its ‘true’ location. Knowledge of the corresponding time histories also allows accurate velocities and accelerations to be calculated, which are particularly important when evaluating the effects of task constraints (e.g. surface types and conditions and bowling speeds) on grip force dynamics.

Note

- 1 Owing to the lack of research into women’s cricket, this chapter will focus on the existing research into the men’s game. For this reason, the traditional terms *batsman* or *batsmen* will be used throughout the text.

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