BIOMECHANICS:

Its Role in Sports Performance

Bruce C. Elliott (Ph.D.)
Department of Human Movement and Recreation Studies
University of Western Australia

Geoffrey Dyson described movements with particular emphasis on track and field athletic phenomena in terms of mechanics without any suggestion to totality or finality. For inevitably one's description must also be subject to the discovery of new data and a more refined presentation of evidence (Dyson, 1967, p.5).

This paper, as a tribute to the applied research of Geoffrey Dyson and to the philosophy of the International Society of Biomechanics in Sports, discusses how biomechanics can assist teachers and coaches to improve sports performance at all levels.

Biomechanists believe that an awareness of the mechanics of movement will better equip and prepare athletes to learn, teachers to teach and coaches to detect and correct flaws in sports performance. An understanding of movement biomechanics enables the teacher or coach to:

- integrate technique modifications with the body anthropometry and flair of the athlete so as to improve performance by focusing on those aspects of mechanics and individual characteristics which are important;
- select the appropriate equipment for body size so that optimal performance at all levels of development can be achieved, and
- reduce the possibilities of overuse or impact injuries through an appreciation of the force absorption requirements of a particular skill.

The biomechanists often uses sophisticated equipment to provide quantitative data on areas of sporting concern so that these data can he integrated with the intimate qualitative understanding of a particular movement possessed by the coach to provide the foundations of a mechanical base to a specific movement. This blending of the science provided by the biomechanist and the art of a particular skill provided by the coach will only occur if data are presented on topics perceived by coaches as important for sports performance. This should not stop biomechanists researching sporting movement on a theoretical level, providing that the implications of such research are presented not only to the academic community but translated into coaching parlance. Too often excellent sports research published in refereed journals is not re-presented in a modified format for teachers and coaches. The many technique errors in the coaching literature bear testimony to the fact that research data either have not been made available or have been misunderstood by coaches. Editors of applied journals must accept some responsibility for this lack of information, as they are often reticent to publish any material of a so-called "theoretical nature".

Armed with an understanding of the biomechanical basis of a particular skill and the ability to evaluate the skill being performed the coach can make the appropriate technique modifications and select the equipment that will allow the development of performance with a minimal risk of injury. The manner that biomechanical data can assist the teacher/coach to establish the correct mechanics for selected sporting skills will now be discussed.

1. TECHNIQUE

Technique analysis and development are the major concern of the sport biomechanist. The first step in understanding a particular sporting activity is to obtain a quantitative descriptive analysis of that movement. Descriptive biomechanics of activities that have not previously been analysed or have been analysed using outdated techniques are still essential. The majority of research today, however, should also address the issue of the underlying forces and torques that cause a particular movement. Computer simulation, where a mathematical representation of the body is formed such that the effect of changing a certain aspect of its structure or motion can be determined, or optimization, where a criterion such as the minimum energy requirement for a given activity dictates movement patterns for a given athlete, may also be used to assist coaches to modify technique. Examples of each of these approaches have been included.

A. DESCRIPTIVE ANALYSIS

A number of descriptive studies that have been of benefit not only to other biomechanists, but also to coaches, are reviewed. Biomechanical research on elite pitching actions have clearly shown that the curveball is thrown with the hand In a marginally more supinated position at release than the fastball (Atwater, 1977). An uneven pressure distribution is then applied to the "outside upper quadrant of the ball" during the release phase. This uneven pressure distribution at release produces a combination of topspin and sidespin on the ball. Forearm pronation, not supination, than occurs during the early follow-through action of this pitch (Elliott et al., 1986A). These research findings clearly demonstrate an opposing view to that reported in many coaching guidelines where the pitcher is encouraged to supinate the forearm and turn the back of the hand to the target to produce ball rotation. Coaches who use these incorrect guidelines not only produce poor results but may risk injuring the pitcher.

Descriptive research by Elliott et al. (1986B) clearly demonstrated the role of the lower limb drive in the tennis service action. This drive increased the angular displacement of the racquet loop during the backswing phase of the stroke and therefore provided a greater distance over which the racquet could be accelerated for impact. These data not only changed the way that coaches should teach the service but also clearly provided players with evidence of the need for lower limb action in their service techniques.

In tennis, the forehand technique used by many world ranked players indicates that individual segments of the hitting-limb appear to be used to generate racquet velocity unlike a conventional forehand where the upper limb appears to act more as a single unit. A group of players who used the multi-segment forehand recorded higher levels of elbow flexion and wrist flexion at impact than the players who used a conventional stroke (Elliott et al., 1989A). This led to a higher racquet tip velocity and post-impact ball velocity for the multi-segment group. As clear description of the segment movements for these two forehand drives should be of great assistance to coaches, who must decide not only how, but when to teach this technique and to biomechanists who may wish to research selected aspects of this stroke.

Richard Smith and his associates (1988) have combined descriptive research and visual feedback to assist coaches and rowers to improve performance. A rower is presented with his forcelangle profile compared to a template which is the rower's best profile from previous tests. The rower is then instructed in technique changes which will modify the forcelangle profile recorded during a six-minute maximum effort on an ergometer to better correspond to the optimal profile. The rower can then practise on an ergometer to associate the movements required to make improvements with the shape changes on an oscilloscope screen.

Descriptive technique analysis should not therefore be a "dirty word" In research but should form an initial stage in the biomechanical analysis of all skills.

B. CAUSAL ANALYSIS

The cause-effect relationships in movement are the cornerstone of applied research. The issue of whether a skilled baseball pitcher drives toward the plate over a stabilized front limb or drives prior to front limb stabilization has not been adequately addressed in the literature. Earlier descriptive analysis of pitching actions have not helped to clarify this question. Cinematographic and dynamometric data from eight International pitchers (Elliott et al., 1988) showed that mean resultant vertical forces were similar for the three fastest pitchers when compared to the three slowest pitchers, however, the slower group produced the peak resultant force earlier in the action, thus reducing the ability to drive over a stablized front limb. Coaches armed with this knowledge are better able to teach the correct timing of this very complex activity.

Despite the extensive use of the bench press in almost every training regime, there is a paucity of published research directed towards the mechanical understanding of this movement. The studies completed have identified a "sticking point or region" where the lifter experiences apparent difficulty in exerting force against the bar. A cinemeatographic and electromyographic study by Elliott et al. (1989B) on elite powerlifters while bench pressing 80% of maximum, a maximum load and an unsuccessful supra-maximal attempt provided some insight into the "sticking region phenomena". The resultant moment arm of the weight about the elbow axis decreased throughout the initial portion of the ascent of the bar recording a minimum value during the sticking region, and subsequently increased throughout the remainder of the ascent of the bar. The electromyograms showed that the prime mover muscles achieved maximal activation at the commencement of the ascent phase of the lift and maintained this level essentially unchanged throughout the upward movement of the bar. The sticking region therefore did not appear to be caused by an increase in the moment arm of the weight about the shoulder or elbow joints, nor from a minimization of muscular activity during this region. A possible mechanism which envisaged the sticking region as a force reduced transition phase between a strain energy assisted acceleration phase and a mechanically advantageous maximum strength region was postulated. The timing of the pause during the descent and ascent phases of the lift and influence this pause has on utilization of strain energy in the subsequent lift is at present being researched. This research addresses a key issue In movement, that of the role played by strain energy in enhancing a movement following an eccentric contraction.

C.1. *OPTIMIZATION/SIMULATION*

In the past it has been the athlete or coach who invents a new technique, or modifies and improves existing techniques. Biomechanists have slowly begun to assist the coach in this area. Nissinen et al. (1983) constructed a model for gymnastic movements to improve and/or modify already existing performances and then finally to develop entirely new movements. The data from a double/back somersault dismount on the horizontal bar provided the input for the simulation of the more difficult movement of the triple-back somersault dismount. The simulation showed that this new skill could be performed with the same initial biomechanical conditions. Coaches aware of these facts were able to teach this new skill relatively quickly, without fear that they were progressing beyond the gymnast's capabilities and thus increasing the possibiltiy of injury.

Jarvis and Marshall (1987) used data from a single and double flyaway from the high bar for a simulation procedure that predicted the variations in biomechanical parameters at release and during flight that must occur for a triple somersault to be performed. The identification of such key variables as; the vertical velocity at release and the body angle to the horizontal at release then enabled coaches to modify the appropriate variables in improving performance. In this way results from simulation studies can be a great assistance to all coaches whereas sophisticated individual research such as that by Nissinen et al. (1983) may best be suited to Institute of Sport based research and coaching programs.

2. STRESS REDUCTION

Biomechanical research requires relation ships to be drawn between the kinetics of an activity, the incidence of pain, and the site and type of injury. Potential causes of stress such as overuse, misuse through poor technique, poor physical preparation and/or genetic predisposition, must all be throughly investigated. The following two applied research papers are discussed as they show how biomechanists and coaches can work together to reduce the likelihood of injury.

Stress fractures to the lumbar vertebra(e) of young fast bowlers in cricket in Australia have reached near epidemic proportions. A series of studies on the fast bowling action were therefore undertaken in an endeavour to identify the relationship between bowling technique, the forces associated with each delivery and back injuries in cricket (Elliott and Foster, 1984; Elliott et al., 1986C). These studies culminated in a prospective study where 82 young fast bowlers were tested prior to the season and all cricket related injuries over this season were assessed by a sports physician, who used computerised tomography to assist in the diagnosis of spinal injuries (Foster et al., 1989). At the completion of the season players were grouped according to their injury status (Group 1 - bony injury to the vertebra; Group 2 - soft tissue injury to the back that caused the player to miss at least one match and Group 3 - no injuries). Eleven percent of the players from this study sustained a stress fracture, while 27% sustained soft tissue injuries to the back that caused them to miss at least one game. No significant differences in ground reaction forces were recorded between the groups, although mean vertical and horizontal levels at front foot impact of 5.4 BW and -2.7 BW respectively were high. Nineteen of a sample of 32 players (59%), who bowled in excess of the mean number of matches for the group were injured compared to the 38% injury frequency for the total group. Selected biomechanical differences, particularly with reference to shoulder rotation and a hyperextended back position adopted primarily by the injured bowlers were identified. Firm recommendations to coaches advocating the teaching of either a side-on or front-on technique but not a mixture of these two styles along with a sensible approach to the number of overs bowled and an appropriate physical preparation should greatly reduce the likelihood of injury.

Gymnastics, like cricket, is a dynamic sport that is enjoying increasing popularity. Unfortunately, there has been a concomitant increase in injuries with an alarming number affecting the lower extremity, specifically ruptures of the Achilles tendon and anterior cruciate ligament. This suggests the occurrence of excessive anterior/posterior loads which may exceed the performers' musculoskeletal tolerance levels. One aspect of a biomechanical study by Panzer et al. (1987) addressed the issue that these loads may be reduced if the gymnast was permitted to land with flexed knees following a double-back somersault from a roundoff-backhandspring entry. Vertical and horizontal ground reaction force data of approximately 12 BW and -5.8 BW respectively were recorded at impact for an extended limb landing from this skill. The majority of landings for all subjects produced symmetrical loadings on both feet, however, the greatest loads (up to 14.4 BW and -8.8 BW for vertical and horizontal forces respectively) occurred in an asymmetrical, yet reasonably successful performance. Nigg (1977) found that a landing technique which allowed greater knee flexion reduced the vertical load transmitted to the knee and hip joints. Data from Panzer et al. (1987) supported these findings, however, the reduction of approximately 2 BW in both vertical and

horizontal reaction forcer, and the fact that the anterior **shear forces** at tho knee joint were increased in the flexed position for some subjects suggests that this technique variation is not the answer in reducing the incidence of injury. The absorption properties of landing materials, therefore need to be improved so that coaches can develop advanced skills in a more injury free environment. Good landing techniques must also be taught if the incidence of injury is to be reduced.

The reduction in the levels of force that must be absorbed during activity through technique modification or by the use of protective equipment must be key areas of concern for all sport biomechanists.

3. EQUIPMENT DESIGN

The physical characteristics of equipment have a direct bearing on how movements **within** given sporting activities are performed. Biomechanics has played an integral role in the development of sporting equipment that has not only decreased the likelihood of injury but has improved performance. Research studies or review articles by:

- **McMahon** and Greene (1979) on the relationship between track compliance, the kinematics of gait and running velocity;
- Nigg (1986) and Cavanagh (1980) on the many influences of running shoe design on gait characteristics;
- **Putnam,** Hay and Wilson (1977) on design characteristics for the uneven bars in women's gymnastics;

are just a few instances where biomechanics research into equipment design has been of great assistance to both the coach and athlete. The following applied studies give some idea of the way biomechanics research has played a role in tennis equipment design. Research into the ultimate **"weapon"** of the game, the racquet (materials used and shape), is not addressed as so much of this research is completed in privately funded laboratories where results are not made public.

A. TENNIS RACQUET SELECTION: A FACTOR IN EARLY SKILL DEVELOPMENT

It has been reported that a marked disparity often exists between the physical characteristics of young players and the racquets they use during class lessons or general play. Preliminary results suggested that an enhanced performance resulted when the physical characteristics of the player and the racquet were matched. Ward and Groppel **(1980)** investigated the influence of different length tennis racquets on the stroke mechanics of the forehand drive of eight year old children, unfamiliar with the game of tennis. Results showed that these young players swung a small racquet(58.4 cm, 370 g) with a higher horizontal velocity and less vertical velocity than did subjects using a longer racquet (68.6 cm, 370 g). Some players showed an inability to control the longer racquet (higher moment of inertia) during the forward swing phase of the stroke and all players using the smaller racquet were able to achieve a more vertical racquet face at impact than the players using the longer racquet.

Elliott (1981) further investigated the influence of racquet size on the learning of tennis skills in young children aged between seven and ten years, who had no previous tennis coaching or playing experience. Tennis-playing ability, as measured by the Hewitt revision of the Dyer tennis test, and on-court performance tests showed that those children taught with smaller racquets (61 cm) achieved superior results on almost all tests compared to those taught with a larger racquet (66 cm). Only in the volley tests, where the swing moment of inertia of the racquet was of minor concern to the stroke (mininal backswing) were similar results recorded using the longer racquet.

Both students clearly demonstrated the need for racquet size to be generally related to body size as indicated by age. Neither study, however, totally answers the problem of racquet selection in relation to body size and strength.

B. STRING TYPE AND TENSION

String type, tension, and the interaction of tension and racquet flexibility, have all been researched in an effort to provide greater insight into equipment characteristics. Gut strings have a slight advantage over synthetic strings in their ability to store energy from the incoming ball and then return this energy to the ball (Plagenhoef, 1970; Groppel, 1983; Ellis et al., 1978). Pouzzner (1969) and Brody (1985) concluded that gut was more resilient than nylon. The small difference in the rebound coefficient is affected by this resilience and by the rougher texture of the gut which reduces string movement when compared with the synthetic material, and thus less energy is probably dissipated through friction.

The question that has often been posed to relate string tension and rebound coefficients (velocity of the ball post-impact compared to pre-impact) is whether to string one'sracquet tighter for more control or for more power. Bosworth (1981), an acknowledged authority on the interaction of rebound coefficients and string tension, and racquet flexibility proposed the following guidelines.

(1) String the racquet at the upper end of the manufacturer's tension range for control and at or below the lower end of the range for power.

(2) A stiff racquet frame requires a higher tension than does a more flexible frame, if the tension is to complement the design characteristics of the frame.

These guidelines have, in fact, been substantiated by research findings. Ellis et al. (1978) varied string tensions from 222 to 289 N for oversized and regular racquets of similar flexibility, while Groppel (1983) varied tensions from 178 to 311 N in fixed racquet. The higher rebound coefficients were obtained for the lower string tensions where the strings deflected more during impact. Brody (1979) further proposed that the greater the energy maintained in the strings, the greater would be the rebound coefficient, provided the time of ball-contact matched the half-period of oscillation of the strings. Groppel (1984), after filming impacts at 4500 frames s^{-1} reported that an increase in string tension caused the ball to "flatten out", which in turn embedded the strings further into the nap of the ball, than would occur for lower tensions. It was suggested that this greater embedding led to a greater ball control.

Baker and Wilson (1978), in a study where a clamped static racquet was struck by balls with pre-impact velocity of 45 m s^{-1}, reported that stiff racquets were not significantly influenced by differing string tensions (178 to 267 N). Medium and flexible racquets had the highest ball velocities after impact when strung at 222 N. Elliott (1982) further investigated the interaction of string tension and racquet stiffness using a pneumatically driven racquet arm and a ball machine for centre and off-centre impacts. String tension had no significant influence on rebound velocity for a stiff racquet with an inward ball velocity of 22.7 ms^{-1} and a racquet velocity of 6.8 ms^{-1}. Medium and flexible racquets produced the highest rebound coefficients for both centre and off-centre impacts when strung at 245 N when compared to 289 and 334 N. Flexible racquets should therefore be strung at higher tensions. However, if the player prefers a flexible racquet and has problems with ball control, then a higher tension may be of assistance.

All the above findings provide coaches and teachers with information that should not only improve their ability to effectively teach stroke production, but should also improve performance by matching racquet characteristics with the individual characteristics of play.

CONCLUSION

As the flying instructor told Jonathan Livingston Seagull - "find perfection and show it forth...we choose our next world through what we learn in this world. Learn nothing and the next world is the same as this with all the same limitations and lead weights to overcome' (Bach, 1972). Geoffrey Dyson encouraged biomechanists to work with teachers and coaches to seek perfection. Biomechanists have at least in part met Geoffrey's challenge by providing research data in the areas of technique development reduction of stress and equipment design. However, if we are to achieve the goals set by people of vision we need to continually remind ourselves that biomechanics will only have a viable future in athletic endeavour if pertinent research questions are addressed and then the results are presented so that sport performance at all levels from the elite performer to the disabled, can be improved.

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