CAUSAL MECHANISMS FOR IMPROVED PERFORMANCE OR INJURY REDUCTION: AN ESSENTIAL PART OF SPORTS BIOMECHANICS RESEARCH

Bruce C. Elliott
The Department of Human Movement, The University of Western Australia, Australia

INTRODUCTION

The need to attract grants to support research efforts has caused many sport biomechanists to change direction and commence projects in exercise rehabilitation, gait and clinical biomechanics. The opportunity to publish sports biomechanics research in international journals is also diminishing and many university administrations do not consider "coaching journals" as representing a quality publication.

We must therefore ensure that our research efforts have relevance. Three-dimensional descriptive studies are always a good starting point in the analysis of movements that have not received research attention. Similarly optimization / simulation projects "that address a suitable hypothesis" are also important. However, two of our primary roles must be to reduce the incidence of injury through identification of "offending" movement characteristics (prospective studies) and improve athlete performance by providing coaches with an appreciation of movement techniques that are of benefit. In this paper, I will briefly review a number of examples of how sports biomechanics research can identify causal mechanisms to peak performance and injury reduction. I will also stress the need for a team approach to sport biomechanics research, so that we can enhance the quality of our research questions and potential for success in attracting grants.

IDENTIFICATION OF KEY MOVEMENT PARAMETERS IN THE TENNIS SERVE

A. **The role of 'leg drive" in the serve:** Lower limb and trunk movements drive the racket-shoulder upward and forward such that an equal and opposite reaction (eccentric force) about this joint produces a negative linear velocity of the racket (Elliott et al., 1986). At a time when the hip and shoulder recorded maximum mean velocities (8 players) of 1.4 m s^{-1} and 1.7 m s^{-1} respectively, the racket-tip was moving downward with a mean velocity of -5.8 m s^{-1}. Those of the group classified as having a good "leg drive" produced a near maximum negative racket velocity of -7.5 m s^{-1}

when the shoulder produced its peak upward velocity.

The recovery of visco-elastic energy stored during this action if there is no, or minimal, pause between the stretch-shorten cycle, permits a high racket speed to be developed for impact. A minimal pause is required as Wilson et al. (1991) had shown that the dissipation of visco-elastic energy with increased pause time for upper limb musculature is represented by a negative exponential equation with a 0.85 s half-life of decay. Therefore, after a delay of approximately 1 s, 55% of stored energy is lost and after a 4 s delay almost all the stored visco-elastic energy is lost. The good leg drive also increases the range of motion (from the completion of the backswing to impact) thus further enhancing the potential to produce a high impact racket velocity.

B. The role of upper arm internal rotation in velocity generation: One of the goals in tennis is to produce a high racket speed at impact in the service action. A number of papers have looked at the role the muscles of the trunk and upper limb play in creating this high speed. Van Gheluwe and Hebbelinck (1986) identified the deltoid, pectoralis major and lattissimus dorsi muscles as being active in the service action. Medial rotation of the upper arm (the rotational movement resulting from these muscle actions) was therefore linked to high speed movement in the serve. This movement was first identified as being a key feature in the service actions of 3 skilled players by Van Gheluwe et al. (1987). Elliott et al. (1995) quantified this influence and showed that internal rotation of the upper arm was responsible for approximately 50% of the impact racket forward velocity. The peak mean internal rotation angular velocity which was recorded 0.006 s prior to impact, showed that this movement occurred very late in the forward swing to impact. The high levels of internal rotation at ball impact of 33 rad s^{-1} (Elliott et al., 1995) was of a similar level to the range of values (20 to 30 rad s^{-1}) that Kibler and Chandler (1994) reported were associated with a high velocity service action. Therefore EMG and cinematographic techniques have both helped to identify a key variable in the tennis serve.

Mont et al. (1994) showed that serving speed increased by approximately 11% for groups who trained the internal and external rotators of the upper arm either concentrically or eccentrically on an isokinetic machine when compared to a control group, whoimproved by 1%. Specific training of a key movement was therefore shown to be a benefit to performance, although the study did not show the improved serving velocity was a result of higher internal angular velocity of the upper arm. All the above information can then be used by coaches to better prepare players, while sports medicine personnel can plan better conditioning programs to improve performance and rehabilitation programs for players returning to health following an injured shoulder. Such programs are essential as Kibler and Chandler (1994) have clearly shown both the importance and the stresses placed on the shoulder region during high performance serving.

THE IDENTIFICATION OF MOVEMENT CHARACTERISTICS THROUGH PROSPECTIVE STUDIES THAT LEAD TO INJURY

A. Lumbar injuries to fast bowlers in cricket: A prospective study tracked 82 high performance 16-to 17-year-old fast bowlers for one year in an attempt to relate movement mechanics with bony/soft tissue injury to the lumbar spine (Foster et al., 1989). Eleven percent of the group sustained a stress fracture to a vertebra(e) (L4 to S1), while 27% sustained a soft tissue lower back injury. Bowlers who counter-rotated the trunk to re-align the shoulders with the direction of ball propulsion by a large amount (≈40°) were more likely to sustain back injuries than those who retained their alignment at back foot impact prior to rotating in the direction of the delivery. When 18-year-old bowlers were similarly assessed it was shown that 55% and 65% had bony (including pedicle sclerosis) and disc abnormalities respectively (Elliott et al., 1992). While the appearance of these abnormal radiological features was attributed to a combination of factors, bowlers who had larger levels of counter-rotation of the shoulder alignment were again more likely to sustain a back injury. A further study attempted to identify changes in radiographic abnormalities (to the disc through MRI, because of age of subjects) over time. Nineteen young fast bowlers (mean 13.6 years) had their bowling action and the status of their lumbar discs biomechanically and radiologically assessed at the beginning of a season. Two and a half years later all bowlers were again tested using an identical protocol (Burnett et al., 1996). The progression of disc degeneration (21% to 58%) was found to be significantly related to those bowlers who counter-rotated their shoulder alignment at both testing sessions. Engstrom et al. (1996) have complemented this work by measuring the area of muscles (from MRI) on both sides of the lumbar spine to assess the influence of muscle asymmetries on bony and disc abnormalities.

B. Stress fractures to track and field athletes: Prospective studies followed 58 male (Brukner et al., 1995) and 53 female (Bennell et al., 1994) track and field athletes (no throwers) for one year. The majority of these athletes, who had mean ages of 20.3 years and 20.5 years respectively, had achieved Australian qualifying standards. On average males and females trained approximately 12 hours per week, while also running 53.7 and 40.7 kms per week respectively. Baseline testing included: bone mineral density, bone mineral content (x-ray absorptiometry), total body fat, lower limb lean mass, dietary calcium, general diet, selected physical and health measures. All athletes with a suspected stress fracture, as assessed by a sports physician, underwent a technetium 99 - labelled isotope bone scan (diagnosis confirmed on a CT scan).

Fourteen stress fractures were sustained by 10 female (incidence 21.7%) and 12 male athletes (20.4%). The risk of fracture in the female athletes increased by a factor of 2.6 for every additional year of age at menarche ($p=0.02$) and by a factor of 1.7 for every 1% decrease in lower limb lean mass ($p = 0.03$). The fracture group also had less menses per year than the non-fracture group. The menstrual factor could influence stress fracture risk by decreasing circulating oestrogen levels, which in turn may alter bone remodelling and bone mineral density. Lower limb lean mass, an indicator of muscularity, may reflect diminished shock absorbing capacity and thus a higher risk of fracture. No significant differences were found between male athletes, who sustained a fracture, compared to those who remained injury free. Although bone density was not a stress fracture predictor, the fracture group showed a trend towards lower bone mass at many regional sites, in particular, the tibia/fibula, which was the most common site of stress fracture. A biomechanical assessment of running, jumping and/or hurdling technique(s) if included in the above studies would possibly have enhanced the chances of identifying causal mechanisms of injury.

CONCLUSION

Sports biomechanists must look for opportunities to broaden their influence. We must convince coaches that we are able to make a difference and educators that "good technique" will lead to improved performance and more enjoyment. We must identify causal mechanisms with reference ta injury and design studies that clearly show that the incidence of injury can be reduced, A team approach to the above problems will certainly enhance our ability to structure meaningful studies in sport biomechanics.

REFERENCES

Bennell, K., Malcolm, S., Thomas, S., McCrory, P., Brukner, P. & Wark, J., (1994). A prospective study investigating risk factor for stress fractures in female track and field athletes, Australian Conference of Science and Medicine in Sport, Sports Medicine Australia, Brisbane, Abstract.

Brukner, P., Bennell, K., Malcolm, S., Thomas, S., Ebeling, P. & Wark, J., (1995). Aprospective study investigating risk factors for stress fractures in male track and field athletes, Australian Conference of Science and Medicine in Sport, Sport Medicine Australia, Hobart, Abstract.

Burnett, A., Khangure, M., Elliott, B., Foster, D. & Hardcastle, P., (1996). Thoracolumbar disc degeneration in young fast bowlers in cricket : a follow-up study, Clinical Biomechanics, 11(6), 305-310.

Elliott, B., Marsh, T. & Blanksby, B., (1986). A three-dimensional cinematographic analysis of the tennis serve, International Journal of Sports Biomechanics, 2 (4), 260-271.

Elliott, B., Hardcastle, P., Burnett, A. &Foster, D., (1992). The influence of fast bowling and physical factors on radiological features in high performance young fast bowlers, Sports Training Medicine and Rehabilitation, 3, 113-130.

Elliott, B., Marshall, R. & Noffal, G., (1995). Contributions of upper limb segment rotations during the power serve in tennis, Journal of Applied Biomechanics, 11(4), 433 - 442.

Engstrom, C., Walker, D., Hanna, A., Kippers, V., Hunter, J., Neal, R. & Wallace, R. (1996). Morphometry of the para-spinal muscles in junior cricket fast bowlers, Australian Conference of Science and Medicine in Sport, Sports Medicine Australia, Canberra, Abstract.

Foster, D., John, D., Elliott, B., Ackland, T. & Fitch, K., (1989). Back injuries to fast bowlers in cricket : A prospective study, British Journal of Sports Medicine, 23(3), 150 - 154.

Kibler, B.W. & Chandler, J.T., (1994). Racquet Sports. In Fu, F. & Stone, D. (Eds.) Sports Injuries. Baltimore: Williams and Wilkins, pp. 531-550.

Mont, M.A., Cohen, D.B., Campbell, K.R., Gravare, K. & Mathur, S.K., (1994). Isokinetic concentric versus eccentric training of shoulder rotators with functional evaluation of performance enhancement in elite tennis players, The American Journal of Sports Medicine, 22(4), 513-517.

Van Gheluwe, B. & Hebbelinck, M., (1986). Muscle actions and ground reaction forces in tennis, International Journal of Sport Biomechanics, 2 ,88 - 99.

Van Gheluwe, B., de Ruysscher, I. & Craenhals, J., (1987). Pronation and endorotation of the racket arm in a tennis serve, In B. Jonsson (Ed), Biomechanics X-B, Champaign, Il: Human Kinetics, pp. 667-672.

Wilson, G., Elliott, B. & Wood, G., (1991). The effect on performance of imposing a delay during a stretch-shorten cycle movement, Medicine and Science in Sport and Exercise, 23(3), 364 - 370.