THROWING: FUNDAMENTALS AND PRACTICAL APPLICATIONS

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This paper focuses on those sports or events in which the participant throws, passes, bowls or shoots an object from the hand and discusses the factors that influence improving the performance of throwers and reducing their time off through injury. In the context of improving performance, the paper evaluates optimum release models, proximal-to-distal sequencing and the role of movement variability. Consideration is also given to technique factors that cause injury and how their effects might be avoided or reduced.

KEY WORDS: Throwing, Performance improvement, Injuries

INTRODUCTION: This paper focuses on those sports or events in which the participant throws, passes, bowls or shoots an object from the hand. The similarities between these activities and striking skills – such as the tennis serve – make much of the research into the latter also relevant to applied work in throwing.

Throwing movements are often classified as underarm, overarm or sidearm. This paper will concentrate on overarm throws; much of the material presented can be extrapolated to underarm or sidearm throws. Overarm throws are characterised by lateral rotation of the humerus in the preparation phase and its medial rotation in the action phase (e.g. Dillman *et al*., 1993). This movement is one of the fastest joint rotations in the human body. The sequence of movements in the preparation phase of a baseball pitch, for example, include, for a right-handed pitcher, pelvic and trunk rotation to the right, horizontal extension and lateral rotation at the shoulder, elbow flexion and wrist hyperextension (Luttgens *et al*., 1992). These movements are followed, sequentially, by their anatomical opposite at each of the joints mentioned plus radio-ulnar pronation. As Bob Marshall's paper (Marshall, 2000) shows, the long-axis rotations of the arm do not fit easily into the assumed proximal-to-distal sequence of the other joint movements.

The mass (inertia) and dimensions of the thrown object - plus the size of the target area and the rules of the particular sport - are constraints on the movement pattern of any throw. Bowling in cricket differs from other similar movement patterns, as the rules do not allow the elbow to extend during the delivery stride. The interpretation of this rule is fraught with difficulty. If the umpires consider that this law has been breached, they can 'call the bowler for throwing': as David Lloyd and Bruce Elliott show in their paper (Lloyd *et al*., 2000), umpires can err in calling throws. One reason for this is that they only have a two-dimensional view of the three-dimensional movements of the arm.

The goal of a throwing movement will generally be distance, accuracy or some combination of the two. In throws for distance, the release speed - and, therefore, the force applied to the thrown object - is crucial. In some throws, the objective is not to achieve maximal distance; instead, it may be accuracy or minimal time in the air. In accuracy dominated skills, such as dart throwing, some passes and free throws in basketball, the release of the object needs to achieve accuracy within the distance constraints of the skill. The interaction of speed and accuracy in these skills is often expressed as the speed-accuracy trade-off. This has been investigated particularly thoroughly for basketball shooting (e.g. Brancazio, 1992). The shooter has to release the ball with speed and accuracy to pass through the basket.

Coaches of throwing events – like all coaches – are particularly interested in improving the performance of their athletes, keeping them performing well and reducing their time off through injury. The following sections are oriented to these coaching goals, which have many implications for the application of sports biomechanics research into throwing.

OPTIMISING PERFORMANCE: In many throws, the objective is to maximise, within certain constraints, the range achieved. Any increase in release speed (v_0) or release height (y_0) is always accompanied by an increase in the range. If the objective of the throw is to maximise range, it is important to ascertain the best (optimum) release angle to achieve this. The optimum release angle (θ), ignoring air resistance, can be found from:

$$\cos 2\theta = g\,y_0 / (v_0^2 + g\,y_0)$$

For a good shot putter, this would give a value around 42°. Although optimum release angles for given release speeds and heights can easily be determined mathematically, they do not always correspond to those recorded from the best performers in sporting events. This is even true for the shot put (Tsirakos *et al.*, 1995) in which the object's flight is the closest to a parabola of all sports objects. The reason is that the calculation of an optimum release angle assumes, implicitly, that release speed and release angle are independent of one another. For a shot putter, the release speed and angle are, however, not independent, because of the arrangement and mechanics of the muscles used to generate the release speed of the shot. A greater release speed, and hence range, can be achieved at an angle (about 35°) that is less than the optimum release angle for the shot's flight phase. If the shot putter seeks to increase the release angle to a value closer to the optimum angle for the shot's flight phase, the release speed decreases and so does the range.

In javelin throwing, some research has assessed the interdependence of the various release parameters. The two for which an interrelationship is known are release speed and angle. Two groups of researchers have investigated this relationship, one using a 1-kg ball (Red & Zogaib, 1977) and the other using an instrumented javelin (Viitasalo & Korjus, 1988). Surprisingly, they obtained very similar relationships over the relevant range, expressed by the equation:

$$\text{release speed (m}\cdot\text{s}^{-1}\text{)} = \text{nominal release speed (m}\cdot\text{s}^{-1}\text{)} - 0.13\ (\text{release angle }(^\circ) - 35^\circ)$$

The nominal release speed is defined as the maximum speed at which a thrower is capable of throwing for a release angle of 35°. In the javelin throw, the aerodynamic characteristics of the projectile can significantly influence its trajectory. It may travel a greater or lesser distance than it would have done if projected in a vacuum. Under such circumstances, the calculations of range and of optimal release parameters need to be modified considerably to take account of the aerodynamic forces acting on the javelin. Furthermore, more release parameters are then important. These include the angular velocities of the javelin at release - such as the pitching and yawing angular velocities - and the 'aerodynamic' angles - the angles of pitch and yaw. A unique combination of these release parameters still exists that will maximise the distance thrown (Best *et al.*, 1995). Away from this optimum, many different combinations of release parameters will produce the same distance for sub-optimal throws. The implications for coaches of this sub-optimal variability and the different 'steepnesses' of the approaches to the optimal conditions have yet to be fully established.

Another complication arises when accuracy becomes crucial to successful throwing, as in shooting skills in basketball. A relationship between release speed and release angle is then found that will satisfy the speed-accuracy trade-off. For a given height of release and distance from the basket, a unique release angle exists for the ball to pass through the centre of the basket for any realistic release speed. Margins of error for both speed and angle exist about this pair of values. The margin of error in the release speed increases with the release angle, but only slowly. However, the margin of error in the release angle reaches a sharp peak for release angles within a few degrees of the minimum-speed angle (the angle for which the release speed is the minimum to score a basket). This latter consideration dominates the former, particularly as a shot at the minimum speed requires the minimum

force from the shooter. The minimum-speed angle is, therefore, the best one (Brancazio, 1992). The role of movement variability - both intra-individual and inter-individual (Hore *et al.*, 1996) - in distance- and accuracy-dominated throws has not been fully explained to date. Stuart Miller's paper (Miller, 2000) outlines his findings – and their implications for coaches - for variability in the kinematics and muscle activation patterns in the basketball free throw, a movement – as noted above – in which accuracy is crucial.
The co-ordination of joint and muscle actions is often considered to be crucial to the successful execution of throwing movements. For example, in kicking a proximal-to-distal sequence has been identified. As kicking has much in common with throwing, we might expect similar distal-to-proximal behaviour for the arm segments in throwing. This is not the case when the movement sequence includes long-axis rotations, as Bob Marshall's paper (Marshall, 2000) shows.

THROWING INJURIES: Throwers subject their bodies to loads well beyond the stresses and strains of sedentary life. The throwing techniques used, even when considered 'correct', may cause injury. The use of many repetitions of these techniques in training should not therefore be undertaken lightly; the risk of injury may well override beneficial motor learning considerations. The use of an incorrect technique is usually considered to exacerbate the injury potential of sports. This has rarely been verified scientifically, although indirect evidence can often be deduced. The sport biomechanist should seek to identify incorrect techniques to prevent injury. Training to improve throwing technique and to acquire appropriate strength and flexibility is likely to help to reduce injury as well as to improve performance. However, many throwing techniques are determined by the activity, reducing possible changes to technique, particularly at high standards of performance.
Low-back pain affects, at some time, most of the world's population and has several causes. These are the weakness of the region and the loads to which it is subjected in everyday tasks, and, particularly, in sport. This involves any of three injury-related activities. These are (Rasch, 1989): weight loading, involving spinal compression; rotation-causing activities involving forceful twisting of the trunk, such as discus throwing; back-arching activities as in many overarm throws. Obviously, activities involving all three of these are more hazardous. An example is the 'mixed technique' used by many fast bowlers in cricket. Here the bowler counter-rotates the shoulders with respect to the hips from a more front-on position, at back foot strike in the delivery stride, to a more side-on position at front foot strike. At front foot strike, the impact forces on the foot typically reach over six times body weight. This counter-rotation, or twisting, is also associated with hyperextension of the lumbar spine. The result is the common occurrence of spondylolysis (a stress fracture of the neural arch, usually of L5) in fast bowlers with such a technique (Elliott *et al.*, 1995). The incidence of spondylolysis and other lumbar abnormalities in fast bowlers is a good example of the association between technique and injury. Relatively few incidences of spondylolysis have been reported amongst genuine side-on or front-on bowlers. It might be hypothesised that incorrect coaching at a young age was responsible. British coaches and teachers have long been taught that the side-on technique is the correct one. However, as the less coached West Indians might be held to demonstrate, the front-on technique may be more natural. Research in both the UK and Australia has demonstrated the injury potential of the mixed technique and convinced the cricket authorities in both countries to amend their coaching texts to reflect this.
In overarm throwing movements, such as javelin throwing and baseball pitching, the joints of the shoulder region often experience large ranges of motion at high angular velocities, often with many repetitions. Overuse injuries are common and frequently involve the tendons of the rotator cuff muscles that pass between the head of the humerus and the acromion process. Examples are tendinitis of the supraspinatus, infraspinatus and subscapularis and impingement syndrome - the entrapment and inflammation of the rotator cuff muscles, the long head of biceps brachii and the subacromial bursa. Other soft tissue injuries include supraspinatus calcification, rupture of the supraspinatus tendon, triceps brachii tendinitis, and rupture or inflammation of the long head tendon of biceps brachii. Elbow injury is possible, particularly towards the end of the preparation phase, where the maximum valgus stress on

the elbow occurs (e.g. Safron, 1995). We have confirmed, using diagnostic ultrasound, many of these injuries in experienced elite British male javelin throwers, with far fewer of them being present in younger top throwers. In overarm throwing for distance, it appears that to achieve the goal of the movement (maximum ball or implement speed), avoiding injury is relegated to second place.

Injuries to the lower extremity, often caused by the trunk twisting or turning while excessive traction fixes the foot, have a technique component in addition to the properties of the shoe-surface interface. The recent trend towards a side facing rather than forward-facing back foot plant in javelin throwing may explain the increasing incidence of patellar tendinitis in the right leg of right handed throwers, Achilles tendinitis and other lower extremity injuries.

CONCLUSIONS: In seeking to maximise the performance of an athlete in a throwing event, we need the correct optimal release model against which coaches can evaluate throwers' performances. In throwing activities, long-axis rotations complicate proximal-to-distal sequencing, which needs to be addressed in devising training schedules. The implications for coaches of sub-optimal variability in throwing and the different 'steepnesses' of the approaches to the optimal conditions have yet to be fully established. Injuries to throwers are mainly overuse. Eliminating injurious techniques, such as the mixed technique in cricket fast bowling, can reduce injuries. However, it appears that to achieve the goal of throws for distance (maximum ball or implement speed), avoiding injury is relegated to second place.

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