FIELD ATHLETICS

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Summary
Field athletics is a group of disciplines which involves jumping and throwing events. This chapter presents the performance indicators of field athletics and their usefulness for coaching and performance optimization. The biomechanical approach appears as a useful strategy for the evaluation of technical patterns in field athletics and their relevance as controllable, trainable and transferable aspects of training.

A methodological strategy for performance analysis in field athletics is presented, underlining the coordination of force application as an important contributor to jumping and throwing ability. In the last part of the chapter, we present the results obtained in the biomechanical analysis of the javelin throw and the long jump, after having considered some of the aspects of the methodology mentioned above.

Introduction
The group of disciplines known as field athletics involves jumping and throwing events, with the main objective of projecting the athlete’s body or an implement, respectively. Jumping includes the long and triple jump, the high jump and pole vaulting, and throwing includes shot put, discus, javelin and hammer. These specialities are characterized by the use of acyclic actions, together with a high level of explosive force and a high projection component aimed at projecting the jumper’s body (jumping events) or an implement (throwing events) as far as possible.

In jumps, the goal is to project the jumper’s mass as far or as high as possible from a fixed projection point. The result of the jump is related to the jumper’s physical ability and capacity to adequately transform and handle, at take-off, the forces generated in the approach run.

In throwing events, the goal is to throw an implement as far as possible. Technical actions are considered to be kinetic chains based on the sequential acceleration of segments in a proximal-to-distal sequence, contributing to the object’s momentum (Putnam, 1993). Based on their characteristics, in some throws, the effect of air resistance on the implement in the flight phase is minimal (shot put and hammer), while in others it is decisive to reaching the longest possible distance (javelin and discus).

Performance in these specialities can be explained by a number of parameters which together make up a specific performance profile. The variables included within sports performance
profiles are typically performance indicators such as selection, combination or action variables that aim to define some or all aspects of performance (Hughes and Bartlett, 2002).

In sports coaching, the general trend is to consider performance and technical achievement synonymous, which implies that good performance requires good technique. However, reality proves that technique alone cannot account for performance. In practice, there are other factors, apart from technique, which add to performance, such as the athlete’s physiological, anthropometric and neuromuscular features (Lees, 2002). As a consequence, the interpretation of the links between technical level and performance must be cautious, especially when the reference is that of an athlete’s individual model (Bartlett, 1999).

The aim of this chapter is to underline the most relevant aspects to bear in mind for performance analysis in field athletics disciplines. As practical examples of this process, long jump and javelin throw are presented as cases, describing the performance indicators used in both specialities.

**Performance analysis of field athletics: a biomechanical approach**

The technical level of the athletes is considered to be a clear determinant of performance. The evaluation of the elements which define a technical pattern of athletes is a fundamental step in sport training. The biomechanical approach appears as a useful strategy for the evaluation of technical patterns in field athletics and their relevance as controllable, trainable and transferable aspects of training. Basically, biomechanics is the science concerned with the internal and external forces that act on a human body and the effects produced by these forces (Hay, 1993).

The importance of biomechanics for coaching and the improvement of performance depend on the sport involved and the level of the athlete:

- **The mechanical characteristics of the sport.** The greater the technical complexity of the actions involved in the sport, the larger the implication of biomechanics. Field athletics groups together a number of disciplines whose technical actions have a high level of complexity.
- **The level of the athlete.** The higher the athlete’s level, the more important his/her technical level. In these cases, performance improvement depends on small details that are difficult to control just through observations by the coach. Biomechanics is therefore essential for an adequate control of the coaching process.

The biomechanical understanding and evaluation of technique involve the consideration of kinematical, kinetic and temporal variables (performance indicators). These include body segment speed or angles, linear and rotational position, displacement and different kinetic variables, such as momentum, force and torque.

The performance profile of a speciality is expressed by hierarchical models based on a cause–effect structure in which parameters are arranged at different levels according to their degree of correlation and influence. All these parameters can be considered as performance indicators, provided that they do meaningfully contribute to the performance. These deterministic models are, in many cases, the best approach to identifying critical features of a movement if we can formulate a clear performance criterion. As examples of such models, Figure 36.1 shows the hierarchical model suggested by Morriss and Bartlett (1996) for the javelin throw.

On the other hand, a biomechanical analysis also implies evaluating the forces generated. Technical actions in field athletics require athletes to use muscular tension of an explosive nature, typical of fast movements and conditioned by a number of factors, such as the following:
• Resistance to be overcome.
• Weight of the throwing artefact. With light weights (javelin throw), maximum tension is reached earlier and decreases as the movement speed grows.
• Force application time. Both in jumping and in throwing events, the application of forces occurs over a very short time. For example, a long jumper who reaches a horizontal velocity in the run-up between 10 and 10.2 m.s\(^{-1}\) uses a touchdown time at take-off between 112 and 136 ms to apply the force (Koyama et al., 2008). This ratio requires a specific physical capacity and ability in the jumper, to be able to transform the horizontal velocity of the run-up into vertical impulse.

In jumping events, the muscular intervention process is more dependent on the participation of the segments involved in the lower kinetic chain:

1. In the take-off phase, the lower kinetic chain (open) makes the most of the action–reaction principle to obtain the take-off force, under Newton’s third law.
2. The small muscle groups take part in the first contact of the foot with the ground, followed by the large and slow ones during the braking of the take-off, and then by the small and fast muscle groups again, thus completing the take-off.

The muscular intervention process in throws is more complex, as a higher number of body segments are involved from both the upper and the lower kinetic chains:

1. At the start of the release phase, the lower kinetic chain (closed) stays in position to take advantage of the action–reaction principle and so obtain the impulse force during the double support phase.
2. Then, the upper kinetic chain (open) works in a sequential way until the most distal segment (the hand) reaches the maximum velocity needed to throw the implement. Thus, it is the large and slow muscle groups of the lower chain that come into action first, followed by...
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by the upper chain and finally by the small and fast muscular groups of the arm’s most distal segments (i.e. the forearm and the hand) to throw the artefact.

Performance analysis strategy in field athletics

Performance analysis is part of the general planning process in coaching and follows a strategic and systematic plan implemented at two levels: (1) evaluation of the athlete’s physical and technical condition; and (2) assessment of performance while competing (jump distance/height and throw distance). The information derived from these two levels of analysis allows us to monitor the athlete’s evolution in the season and to identify the effects of coaching on the improvement of his/her performance.

A. As far as physical condition is concerned, different parameters are evaluated, basically in relation to strength and muscular power:

- general strength for the analysis of the force component of power;
- special strength for the analysis of the capacity to convert general strength into specific strength;
- specific strength for the analysis of the capacity to develop the velocity component of power and to provide power improvement in a way which is specific to the required technique of an athlete.

B. Regarding technique, the goal focuses on evaluation and diagnosis to know what’s right and wrong in a movement (Bartlett, 2007): (1) evaluation of performance; and (2) diagnosis of movement errors. Different performance indicators are used depending on the goal set:

1. **Determination of the individual technical pattern.** The goal is to describe the athlete’s individual model from performance indicators that can be compared with those of the reference theoretical model. Athletes tend to copy the currently most successful performer. Further evidence to this effect has come from research using artificial neural networks – Kohonen self-organizing maps – for javelin and discus throwing by Schöllhorn and Bauer (1998).

2. **Inter-subject analysis.** The goal is to analyse performance indicators of individual models to be able to compare differences between athletes with a different sports level (novice, club, elite).

3. **Intra-subject analysis.** The goal is to determine the internal consistency of the athlete’s individual model, underlining the factors with the greatest influence on his/her performance. For novice, club and elite javelin throwers, Bartlett et al. (1996) reported that intra-individual differences were greater for the novice and the elite throwers than for the club throwers. Neither of these findings, which were again reinforced by the results of Schöllhorn and Bauer (1998), supports the notion of intra-individual movement consistency. Even elite athletes appear unable to produce invariant movement patterns after many years of practice (Bartlett, 2008).

C. On the other hand, the analysis of the evolution of performance in competition consists of describing the reproducibility of competitive performance of athletes and deriving the smallest worthwhile enhancements of performance. An estimate of the smallest change comes from an analysis of reliability (reproducibility or variability) of competitive performance (Hopkins, 2005). We must focus on within-athlete variability from competition to competition to obtain the athlete’s typical percentage variation in performance from competition to competition as a coefficient of variation.
Performance indicators in jumping and throwing

Performance indicators in jumping: the long jump

The first performance indicator in jumping is *jump distance or height*, for a horizontal jump (long and triple jump) or a vertical one (high jump and pole vault), respectively. Jump distance/height is conditioned by the values obtained in these performance indicators:

- run-up speed
- force and wind direction
- take-off velocity
- take-off angle
- take-off height
- the gain of vertical velocity
- the loss of horizontal velocity.

Each jumping discipline requires differentiated values in accordance with its specificity. For instance, the projection angle of the jumper’s centre of mass (CM) in the triple jump ranges from 14° to 18°; between 18° and 22° in the long jump; and between 60° and 65° in the high jump. As a general criterion, the greater the horizontal velocity, the smaller the angle of projection, and vice versa. The larger the angle of projection, the greater the need for adequately holding the horizontal forces generated in the run-up.

Jumping disciplines must also take into account the *foot/ground contact time during the take-off*. The time of contact between the foot and the ground at take-off (take-off time) depends on the technique used and on the jumper’s physical ability. Take-off time correlates negatively with the velocity of the approach run and with the jump distance (Hay, 1986). Therefore, the faster the run-up, the shorter the take-off time and the longer the jump.

Performance in the long jump depends on the actions taken at two decisive phases – that is, the run-up and the take-off. Numerous papers have reported that jump distance depends, to a great extent, on the velocity of the approach run as well as on factors like the projection height, angle and velocity of the jumper’s centre of mass at take-off (Alexander, 1990; Bridgett and Linthorne, 2006; Graham-Smith and Lees, 2005; Hay and Nohara, 1990; Hay and Reid, 1988; Lees et al., 1994; Seyfarth et al., 2000). Regarding the approach run, athletes attempt to strike the take-off board accurately with minimum loss of speed and in an optimum body position for take-off (Hay, 1988). Thus, if the jumper is fast, this condition should be made the most of by increasing the length of the run-up. In the long jump, the run-up distance varies from 45 to 60 m. The athlete’s speed is reduced in the last 5 m and especially in the last two steps of the run prior to the take-off.

The length of the last three strides is also altered in order to favour the transition from running to taking off. In general terms, the structure is such that the second-to-last stride is longer than the other two, the last one being the shortest. It was stated by Hay and Nohara (1990) that elite long jumpers lowered their CM during the flight phase of the second-to-last stride and stayed low until they raised it for the instant of take-off during the support phase of the jump itself.

Regarding the take-off phase, in the long jump, the efficiency of the jump demands a technical strategy based on making the most of the spring behaviour of the take-off leg (Seyfarth et al., 1999). Several studies have stated that performance in the long jump is directly related to different mechanical and muscular mechanisms that occur from the touch-down to the take-off.
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phase. It is well-known that the greatest gain in vertical velocity occurs during the compression
phase, which is associated with a loss of horizontal velocity (Lees et al., 1993).

Table 36.1 shows different performance indicators in the long jump from elite jumpers in
a situation of real competition, where the total gain in vertical velocity was $3.41\pm0.36\,\text{m.s}^{-1}$,
most of it occurring by the end of the compression phase (from touch-down to maximum knee
flexion). During the take-off, the athlete’s horizontal velocity is reduced by $1.33\,\text{m.s}^{-1}$ – that is
12 per cent of the velocity of the approach run (Campos et al., 2008).

In long jump, the data analysis focused on three discrete temporal instants associated with
the take-off phase (Figure 36.2):

- instant of the touch-down, when the take-off foot touches the ground (board) ($TD$)
- instant of the maximum knee flexion ($MKF$)
- instant of the take-off, in which the foot loses contact with the ground ($TO$).

Thus, the following take-off phases can be differentiated in the jump:

- **compression phase**: from touch-down to maximum knee flexion ($TD–MKF$)
- **extension phase**: from maximum knee flexion to take-off ($MKF–TO$).

Table 36.1  Basic data for official and effective distance, approach speed ($V_{\text{run}}$), take-off velocity of centre
of mass at take-off instant ($V_{\text{cm-to}}$), angle of projection at take-off instant ($A_{\text{to}}$) and loss in horizontal
velocity ($V_y$) and gain in vertical velocity ($V_z$) from the instant of touch-down to take-off ($n=22$) (Cam-
pos et al., 2008)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Official distance (m)</td>
<td>7.85±0.14</td>
</tr>
<tr>
<td>Effective distance (m)</td>
<td>7.97±0.14</td>
</tr>
<tr>
<td>$V_{\text{run}}$ (m.s$^{-1}$)</td>
<td>10.48±0.24</td>
</tr>
<tr>
<td>$V_{\text{cm-to}}$ (m.s$^{-1}$)</td>
<td>9.54±0.32</td>
</tr>
<tr>
<td>$A_{\text{to}}$ (°)</td>
<td>20.8±2.08</td>
</tr>
<tr>
<td>$V_z$ gain TD–TO (m.s$^{-1}$)</td>
<td>3.41±0.36</td>
</tr>
<tr>
<td>$V_y$ loss TD–TO (m.s$^{-1}$)</td>
<td>1.33±0.28</td>
</tr>
</tbody>
</table>

Figure 36.2  Representative instants of touch-down, maximum knee flexion and take-off for the long
jump (adapted from Campos et al., 2008)
The landing of the foot of the driving leg on the board generates an energy exchange that is fundamental for the jump performance, especially in the braking impulse (compression phase), when the knee extensor muscles work eccentrically. This phase has been described as a pivot mechanism, characterized by an increase in the vertical velocity of the jumper’s CM at the expense of a reduction of their horizontal velocity; more than 60 per cent of the athlete’s vertical velocity at the take-off is achieved in this phase (Lees et al., 1994). Basically, the jumper’s goal is to generate vertical velocity of CM at take-off without losing too much horizontal velocity of CM.

In the compression phase (TD–MKF), the highest increase in the vertical velocity of the athlete’s CM is achieved, with a subsequent marked decrease in horizontal velocity. Figure 36.3 shows the values of the spatial velocity components of the CM during the take-off phases for a world-class jumper.

Figure 36.3 shows the changes in magnitude of the medio-lateral, horizontal and vertical velocities of the CM for the jumper with the best effective distance result. The lowest values are those of the medio-lateral velocity. The horizontal velocity lowers from the instant of the touch-down and until the end of the compression phase, but its lowest value is reached after the instant of the maximum knee flexion of the take-off leg (8.42±0.30 m.s⁻¹). Then, it recovers slightly throughout the extension phase until the instant of the take-off, when a mean value of 8.96 m.s⁻¹ is reached. In turn, the vertical velocity of the CM shows the opposite behaviour, progressively growing from −0.07 m.s⁻¹ at touch-down to 3.17 m.s⁻¹ at take-off.

Performance indicators in throwing: the javelin throw

In throwing disciplines, the preferred performance criterion is throwing distance. However, the throwing distance is the consequence of interactions between a number of parameters:

- release velocity (Vo)
- release angle (αo)
- height of release (ho)
- rotation of implement
- air resistance and aerodynamic characteristics of the implement

![Figure 36.3](image-url) Medio-lateral, horizontal and vertical velocities of CM in the last stride and take-off phase
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- force and wind direction
- air density
- gravitational coefficient.

If gravity is considered a general constant \((9.81 \text{ m/s}^2)\), in throws in which air resistance has no influence — as is the case with specialties whose artefacts have no aerodynamic features (shot put and hammer) — attention must be paid to release velocity, release angle and release height. In these cases, the distance travelled by the artefact \((R)\) can be estimated by means of equation (36.1):

\[
R = \frac{V_o \times \cos \alpha}{g}
\]  

(36.1)

The angle of projection of the athlete’s CM is conditioned by the horizontal and vertical components of the CM at the take-off instant. It is calculated by the equation (36.2), where \(V_z = \) vertical velocity and \(V_y = \) horizontal velocity:

\[
\text{Projection angle (}\alpha\text{)} = \arctan \frac{V_z}{V_y}
\]  

(36.2)

The performance of a javelin throw is determined by the velocity, direction and height of the javelin at the release, as well as factors affecting the aerodynamics of javelin flight (Bartlett et al., 1996; Hay, 1993). The pattern of motion used in the javelin throw is similar to that used in other movements when striking or throwing an object. These movements are characterized by the fact that the body segments act sequentially to attain the maximum speed in the most distal segment of the system in the instant when the object is struck or thrown (Atwater, 1979; Menzel, 1987). Many studies have described the javelin throwing technique, including those by Bartlett et al. (1996), Best et al. (1993), Campos et al. (2004), Hay (1993) and Whiting et al. (1991).

The biomechanical analysis in javelin throwing for each athlete focused on the period illustrated for the preparatory and final throwing phases. The most important factors for javelin release occur during these decisive periods, which offer the best conditions for comparing the athletes’ techniques.

It is precisely at this final throwing stage that the acceleration of the javelin starts. The upper extremity joint centre linear velocities are the result of the proximal segment and joint angular motions (Gordon and Dapena, 2006). Hence, performance depends on:

1. the optimum position of the kinetic chain at the start of the final throwing phase;
2. the sequence of kinetic power transmission during the final throwing phase.

A factor that influences the quality of energy transfer to the javelin is the coordinated motion of the upper limb, starting from the acceleration–deceleration of the sequences in the upper kinetic chain. Typically, several body segments, in a proximal-to-distal sequence, contribute to the object’s momentum (Putnam, 1993). These sequential motions from the proximal to the distal segments are one of the fundamental keys to performance in overarm throwing. Hip, shoulder, elbow, hand and javelin velocities are taken into account to analyse these power transmission sequences in the final phase.

Figure 36.4 shows hip, shoulder, elbow and javelin velocities in the Finnish thrower Parviainen’s winning 89.52 m throw in the final of the World Championship in Athletics held in Seville in 1999. The analysis of how the maximum peak velocities for each marker are reached at the instant of release (T3) provides a more detailed description of the timing used by the throwers to structure their individual motion models for the upper limb.
The trajectories of the markers presented in Figure 36.4 show that the general throwing model stated by Menzel (1987) is repeated. As a point of reference, an adequate throw is one in which the order of the joint points described reach their maximum velocity peak as follows: first/hip; second/shoulder; third/elbow; fourth/javelin. Two joint points reaching their maximum velocity peak at the same instant is considered to be a sequence error that hinders power transmission towards the most distal segments.

A more recent study has shown that, despite the fact that elite javelin throwers developed maximum joint centre linear velocities of their throwing arm in a proximal-to-distal sequence, throwers did not start their throwing arm segment and joint angular velocities in a proximal-to-distal sequence (Liu et al., 2010). This is an interesting issue that needs further research but one that should be noted for the technical training of javelin throwers.

However, in javelin throwing, there are other factors that affect performance, such as aerodynamic factors. Due to its special design, the javelin has aerodynamic features that affect the flight phase and subsequently the throwing distance. Table 36.2 shows the values of a number of performance indicators of the finalists of the 1999 World Championships held in Seville.

Table 36.2 Kinematic release parameters in elite throwers (Adapted from Campos et al., 2004)

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Distance (m)</th>
<th>Release velocity (m.s⁻¹)</th>
<th>Height of release (m)</th>
<th>Attitude angle (°)</th>
<th>Release angle (°)</th>
<th>Attack angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parvianen</td>
<td>89.52</td>
<td>29.71</td>
<td>2.14</td>
<td>35.7</td>
<td>36.6</td>
<td>−0.9</td>
</tr>
<tr>
<td>Gatsioudis</td>
<td>89.18</td>
<td>29.6</td>
<td>1.90</td>
<td>37.5</td>
<td>31.6</td>
<td>5.9</td>
</tr>
<tr>
<td>Zelezny</td>
<td>87.67</td>
<td>29.21</td>
<td>1.80</td>
<td>36.9</td>
<td>31.1</td>
<td>5.8</td>
</tr>
<tr>
<td>Hecht</td>
<td>85.24</td>
<td>28.54</td>
<td>2.09</td>
<td>41.7</td>
<td>40.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Henry</td>
<td>85.43</td>
<td>28.12</td>
<td>1.99</td>
<td>25.3</td>
<td>32.1</td>
<td>−6.8</td>
</tr>
<tr>
<td>González</td>
<td>84.32</td>
<td>29.37</td>
<td>1.83</td>
<td>36.5</td>
<td>27.7</td>
<td>8.8</td>
</tr>
<tr>
<td>Backley</td>
<td>83.84</td>
<td>28.5</td>
<td>2.08</td>
<td>40.8</td>
<td>35.3</td>
<td>5.5</td>
</tr>
</tbody>
</table>
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Each thrower uses differentiated values. The German thrower Hecht used the largest release angle (40.1°) and the Cuban González the smallest (27.7°). González had the largest resulting attack angle (8.8°) and Parvianen (–0.9°) and Hecht (1.6°) the smallest. Overall, Table 36.2 shows that the athlete who came closest to the reference values was the World Champion, the Finn Parvianen, who was capable of throwing at a release velocity of over 29.5 m.s⁻¹, with a release angle of 36.6°, resulting in a negative attack angle of almost zero.

Concluding remarks

Performance analysis is part of the general planning process in coaching and follows a strategic and systematic plan for the evaluation of the athlete’s physical, technical condition and performance while competing (jump distance/height and throw distance).

Technical level of the athletes is considered to be a clear determinant of performance in field athletics. However, reality proves that technique alone cannot account for performance. This chapter has summarized some relevant aspects of performance analysis in field athletics and has pointed out the potential benefits of the biomechanical approach in analysing different performance indicators in jumping and throwing events.

From the technical point of view, it has been demonstrated that intra-individual differences are greater for the novice and the elite athletes than for the club athletes (Bartlett et al., 1996), supporting the notion of intra-individual movement consistency (Schöllhorn and Bauer, 1998).

Even elite athletes appear unable to produce invariant movement patterns after many years of practice (Bartlett, 2008).

The performance analysis for long jump and javelin throwing shows that an adequate energy transformation requires an adaptive technical model that can solve the problems that athletes face at the time of jumping and throwing based on their strength and ability. Therefore, training should be addressed from an open, individualized perspective to help athletes build an efficient individual technical pattern.

References


