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BIOMECHANICS OF JAVELIN THROWING

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"The author here examines separately each of the four phases of javelin throwing, approach run, release, braking and flight of the javelin; having determined the biomechanical objective and the biomechanical factors of influence of each phase, he illustrates them and adds a number of training hints that may help to achieve the 'maximization of throwing distance' that every athlete pursues."

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1. Introduction

The sport-motor objective of javelin throwing is to attain the greatest possible throwing distance. The athlete tries to achieve this objective, which is generally called the "maximization of throwing distance", via the following throwing elements: approach run, release, braking (final phase), and the flight of the javelin. The approach run and the release are divided into the throwing phases shown in table 1.

For the biomechanical description of javelin throwing a two-dimensional xz-coordinate system is used (Fig. 1) whose x-axis represents in its direction the approach run and the release, and whose z-axis is placed in a vertical relation to the x-axis.

Although the movements of the javelin and the athlete – particularly during the throwing stride – are not always on the same plane (e.g. bending of the trunk towards the side of the braced leg, rotation of the body around the longitudinal axis of the braced leg), there are several reasons for this simplification.

On the one hand, the main movement takes place on one plane, on the other hand measurements generally allow only a two-dimensional way of looking at the throwing movement because of competition-organisational and investigation-economical reasons.

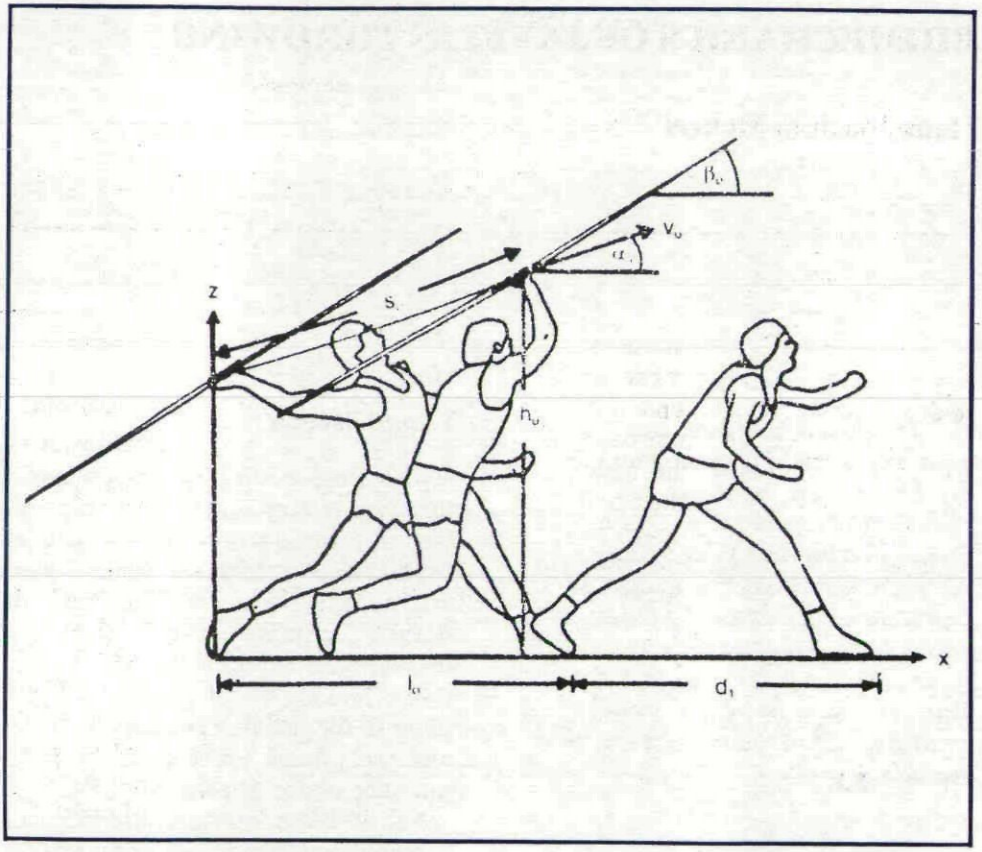

Fig. 1 - Features of length, position, and velocity during the two-legged support and braking phase

Key:

l_o - Length of the bracing stride

d_1 - Length of the final phase: length of the braking stride(s) after the release

s_o - Acceleration path of the javelin (way which is covered by the javelin during the two-legged support phase until leaving the throwing hand)

h_o - Height of release (height of the cord binding at the moment of release)

α_o - Release angle of the javelin (angle between the resulting velocity of release v_o and the horizontal line)

β_o - Angle of attack at the moment of release (angle between the longitudinal axis of the javelin and the horizontal line).

v_o - Velocity of release

Table 1 - Throwing elements and respective throwing phases

Throwing elements	Throwing phases
Approach run	1. Acceleration phase (cyclic approach phase)
	2. Release-preparatory phase (acyclic approach phase)
Release	1. One-legged support phase
	2. Two-legged support phase (bracing phase)
Braking	Braking phase (final phase)
Flight of the javelin	Flight phase

The objective "maximisation of throwing distance" requires an optimal approach velocity at the end of the acceleration phase of the approach run, an optimal position of the body segments and the javelin at the end of the acyclic phase of the approach run (5-stride rhythm), a maximal velocity of release, as well as an optimal attack- and release angle of the javelin at the end of the release phase. A maximal velocity of release requires an optimal impulse transmission (movement transmission) via the segment chain 'hip - trunk - throwing arm - javelin' during the bracing phase.

Because of the impulse transmission, there is a reduction of the velocity of the hip, shoulder, and elbow in favour of the velocity of the throwing hand and the javelin.

2. Approach run

The approach run consists of a cyclic phase (acceleration phase) and an acyclic phase (release-preparatory phase) (Table 1).

Acceleration phase (cyclic approach phase)

Beginning: start of the approach run.

End: start of the javelin withdrawal.

Objective: achievement of an optimal approach velocity.

Comment:

The approach velocity shows an individually different optimal trend, i.e. within a range below the maximal running velocity, the maximal throwing distance is attained; going beyond or falling short of this range has a negative effect on performance. The available investigation results corroborate the finding that there is a covariation between the optimal approach velocity and the throwing distance (Table 2). It must be mentioned, however, that although an optimal approach velocity is necessary, it is not a sufficient prerequisite of a maximal throwing distance.

Biomechanical factors of influence:

1. Length of the acceleration phase
2. Stride length
3. Stride rate

Comment:

On the optimization of the length of the acceleration path: As it is the case with the optimal approach velocity, the optimal length of the acceleration path is dependent on the level of performance. According to *Salomon* (1971), the length of the approach run of world-class athletes (W > 85 m) varies between 26 and 36 m. Their acceleration path is therefore between 18 and 28 m long.

On the optimization of stride length and stride rate: As far as these factors of influence are concerned, the remarks on the corresponding phases of the long jump hold good.

Training hints

On the individual optimal length of the length of the acceleration phase: The individual optimal length of the acceleration path is dependent on the intended optimal approach velocity of athletes of the respective level of performance. In proportion to the increasing approach velocity, there is also an increase in the length of the acceleration path. According to *Bauersfeld/Schröter* (1980), the optimal length of the acceleration path is between 8 and 12 strides.

On the individual optimal approach velocity: Since the approach velocity shows an optimal trend, there has to be first of all information on the intended changes. As far as women are concerned, the approach velocity is between 5.2 and 6.0 m/s or 5.7 and 6.5 m/s (throwing distance: 30 to 40 m or 50 to 60 m, respectively). As far as men are concerned, the approach velocity is between 6.0 and 6.5 m/s or 6.3 and 7.3 m/s (throwing distance: 50 to 60 m or 70 to 80 m, respectively). It is advisable that the fixing of the individual optimum is done by the experimental variation of the approach velocity and the simultaneous determination of the throwing distance. The variation of velocity is regulated via the change of stride length or/and stride rate.

Release preparatory phase (acyclic approach phase)

Beginning: start of the javelin withdrawal (generally the fifth from the last approach stride).

End: beginning of the release (beginning of the one-legged support phase of the bracing stride).

Table 2 - Throwing distance W and approach velocity V_{AN} in the acceleration phase

W *[m]*	V_{AN} *[m/s]*	Group of throwers	Author
>65	6.0-6.5	Female specialists	Bauersfeld/Schröter
52.36-60.76	5.8-6.6	Female specialists	Own investigation
33.06-43.28	5.3-6.1	Pentathletes	Own investigation
>85	8.0-8.5	Male specialists	Bauersfeld/Schröter
67.26-81.16	6.2-7.3	Male specialists	Own investigation
77.84	6.5	Male specialists	Kollath
51.26-68.90	5.4-7.0	Beginners and advanced throwers	Ikegami
50.92-67.06	6.1-6.8	Decathletes	Own investigation

Objective: establishment of biomechanical release conditions which contribute to attaining a great throwing distance.

Biomechanical objectives: an optimal approach velocity at the beginning of the release and a body position at the moment of planting the foot of the throwing-arm side (bracing stride, release), which optimizes the release. An indicator of this body position is the inclination angle of the longitudinal axis of the body at the beginning of the one-legged support phase (landing after the impulse stride, Fig. 2).

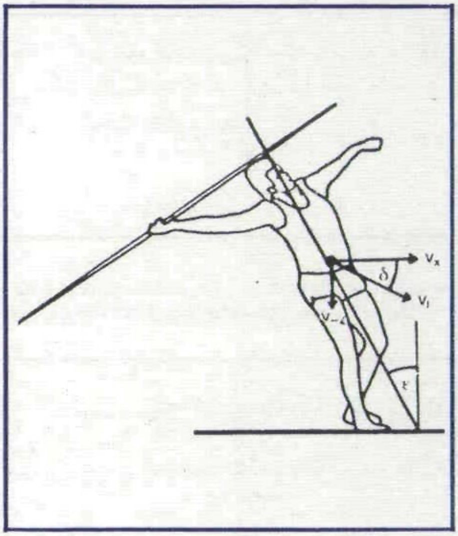

Fig. 2 - Beginning of the one-legged support phase of the bracing stride (end of the release-preparatory approach phase)

Key:

v_l - Landing velocity

v_x - Horizontal velocity

v_{-z} - Vertical planting velocity

δ - Landing angle

ε - Angle between the longitudinal axis of the body and the vertical line (inclination angle)

• - Centre of gravity (CG)

Comment:

According to *Bauersfeld/Schröter,* the optimum values of the inclination of the longitudinal axis of the body as well as of the attack angle are between 30 and 36°, the angle between the shoulder axis and the longitudinal axis being approximately 90°. The further acceleration of the entire system demanded by *Bauersfeld/Schröter* cannot be empirically corroborated by the available data. *Kollath's* (1983) and our own investigation results (Table 3) show that there is a comparatively strong variation of the approach velocity during the acyclic approach phase, so that "the quoted demand for a further acceleration of the thrower and the javelin was not fulfilled" (*Kollath* 1983, p. 90). Obviously, the taking-up of a release-optimizing body position reduces the approach velocity. The biomechanical objective is therefore to reduce the approach velocity as slightly as possible.

Biomechanical factors of influence:

1. Stride length.
2. Landing angle of the impulse stride (last approach stride)

Comment:

As far as the stride pattern is concerned, specialists show a trend to lengthen the impulse stride as compared with the last but two or the last but one approach stride. Multiple-event athletes change the length of the last three approach strides only very slightly (Table 4). The taking-up of an optimal release-preparatory body position is dependent on the way the impulse stride is carried out. In the training-theoretical literature the impulse stride is described as a lengthened but flat stride which places the thrower into an optimum release position (*Bauersfeld/Schröter* 1980). Characteristics of the impulse stride are the vertical planting velocity and the landing angle of the CG (Fig. 2). The available investigation results show that among low-level throwers there is a tendency to a less pronounced inclination of the longitudinal axis of the body and a steeper landing angle of the impulse stride.

Training hints

The carrying-out of the release-preparatory phase is mainly dependent on the length of the impulse stride. If the impulse stride is longer than the last but one approach stride, the conditions of an advantageous position of the body segments can be optimized. A too short impulse stride would lead to a steeper trajectory of the CG. A result of this would be an increase in the height of drop of the CG, which would lead to an increased vertical velocity and an increased landing angle (Tables 4 and 5).

Table 3 - Mean competitive throwing distance $\bar{W}$ and group mean values of velocities v_i (i = 5, .., 1) of the fifth from the last to the last approach stride (impulse stride) of different groups of throwers (own investigation)

$\bar{W}$ [m]	$\bar{v}_5$ [m/s]	$\bar{v}_4$ [m/s]	$\bar{v}_3$ [m/s]	$\bar{v}_2$ [m/s]	$\bar{v}_1$ [m/s]	Group of throwers
56.32	6.0	5.8	6.1	6.0	5.6	Female specialists
36.82	5.8	5.6	5.8	5.7	5.3	Pentathletes
74.64	6.6	6.4	6.6	6.5	6.1	Male specialists
53.60	6.3	6.2	5.9	6.3	5.6	Decathletes

Table 4 - Mean throwing distance $\bar{W}$ and mean stride length of the last but two ($\bar{l}_3$), the last but one ($\bar{l}_2$), and the last approach stride (impulse stride, $\bar{l}_1$) of performance-heterogeneous groups of throwers (own investigation)

$\bar{W}$ [m]	$\bar{l}_3$ [m]	$\bar{l}_2$ [m]	$\bar{l}_1$ [m]	Group of throwers
56.32	1.60	1.67	1.71	Female specialists
36.82	1.33	1.38	1.34	Pentathletes
74.64	1.90	1.87	1.98	Male specialists
53.60	1.64	1.48	1.52	Decathletes

Table 5 - Mean competitive throwing distance $\bar{W}$, group mean values of the vertical landing velocity $\bar{v}_{-z}$, landing angle δ and inclination angle of the longitudinal axis of the body $\bar{\varepsilon}$ of performance-heterogeneous groups of throwers (own investigation)

$\bar{W}$ [m]	$\bar{v}_{-z}$ [m/s]	δ [°]	$\bar{\varepsilon}$ [°]	Group of throwers
56.32	0.9	11	32	Female specialists
36.82	1.1	13	23	Pentathletes
74.64	1.1	11	27	Male specialists
53.60	1.3	13	23	Decathletes

3. Release

Beginning: planting of the bracing leg (throwing-arm side).

End: end of the contact of the hand with the javelin.

Objective: attainment of a maximal throwing distance.

Biomechanical objectives: maximal velocity of release v_o, optimum angles of release (α_o) and of attack (β_o) of the javelin (Fig. 3).

Comment:

The objective of the release is the achievement of an optimum velocity of release v_o as well as an optimum angle of release α_o and an optimum angle of attitude β_o. Because of the aerodynamic flight characteristics of the javelin, which are explained in more detail in the chapter "Flight", a variation of the features "velocity of release", "angle of release", and "angle of attack" has different effects on the throwing distance in dependence of the wind conditions. The velocity of release has the greatest influence on the throwing distance.

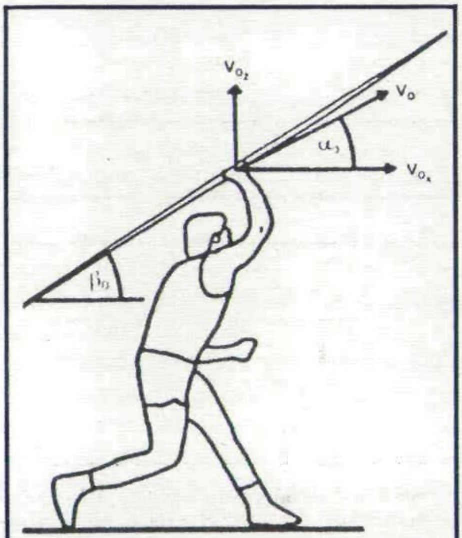

Fig. 3 - Biomechanical objectives of the release

Key:

v_{ox} - Horizontal velocity of release
v_{oz} - Vertical velocity of release
v_o - Velocity of release
α_o - Angle of release
β_o - Angle of attitude

In our own investigations on decathletes and specialists (N = 18), we found a statistically significant correlation between the velocity of release and the throwing distance (r = .97). Because of the material characteristics of the javelin, the optimum angle of release α_o is dependent on aerodynamic conditions. Details about throwing distance and angles of release given by various authors as well as the results of our own investigations are compiled in Table 6.

The investigation results show that because of aerodynamic factors, the optimum range of the angle of release in javelin throwing is characterized by lower values as compared to the aerodynamically largely independent shot put. While *Nigg* et al. (1974) recommend an optimum angle of release of 33-39°, *Terauds* (1976) thinks that an angle of release of 20-35° is optimal. Besides, *Terauds* is of the opinion that an increasing velocity of release goes hand in hand with an increasing optimum angle of release.

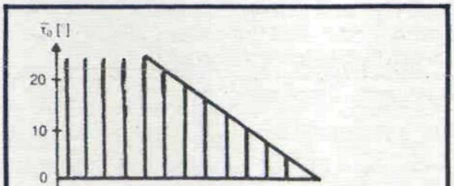

Fig. 4 - Value range of the angle of attack in relation to various throwing distances

Table 6 - Group mean values of throwing distances $\bar{W}$ and angles of release α_o of different groups of throwers

$\bar{W}$ [m]	$\bar{\alpha}$ [°]	Group of throwers	Authors
55.80	36	Female specialists	Own investigation
36.34	38	Pentathletes	Own investigation
84.89	34	Male specialists	Terauds (1978)
80.90	33	Male specialists	Terauds (1975)
78.02	34	Male specialists	Own investigation
77.84	38	Male specialists	Kollath
75.85	37	Male specialists	Miller and Munro
59.30	33	Advanced throwers	Ikegami
56.64	38	Decathletes	Own investigation
53.27	33	Decathletes	Kunz

Table 7 - Group mean values of the throwing distance $\bar{W}$, the angles of release $\bar{\alpha}_o$, attitude $\bar{\beta}_o$, and attack $\bar{\tau}_o$ of different groups of throwers

$\bar{W}$ [m]	$\bar{\alpha}_o$ [°]	$\bar{\beta}_o$ [°]	$\bar{\tau}_o$ [°]	N	Group of throwers	Authors
56.32	36	40	4	7	Female specialists	Own investigation
36.82	38	48	10	8	Pentathletes	Own investigation
80.94	33	40	7	4	Male specialists	Terauds (1976)
84.98	34	38	4	4	Male specialists	Terauds (1978)
74.64	34	36	2	9	Male specialists	Own investigation
53.60	38	47	9	9	Decathletes	Own investigation

Table 8 - Mean angles of attitude $\bar{\beta}_o$ of performance-heterogeneous groups of throwers (Witchey 1973)

$\bar{W}$ [m]	β_o [°]	N
72.62±2.64	40.3±3.3	39
64.68'2.40	42.5'4.8	56
53.60±5.64	46.0±5.3	38

Apart from the angle of release α_o, the angle of attitude β_o (angle between the horizontal line and the longitudinal axis of the javelin) influences the flight behaviour. The difference between the angle of attitude β_o and the angle of release α_o (Fig. 4) is called angle of attack $\bar{\tau}_o$.

According to investigations by *Nigg* et al. (1974) and *Kunz* (1983), great angles of attitude have a negative effect on performance. While *Kunz* (1983, p. 138) summarises his investigation results by saying "that great throwing distances are hardly possible with great angles of attack", *Nigg* et al. give the range of values of the angle of attack in dependence on the attained competitive distance (Fig. 4). In order to attain a great throwing distance, it is advisable to have a small angle of attack, i.e. an angle of attitude which is slightly greater than the angle of release. The investigation results shown in Tables 7 and 8 point out that the aerodynamic prerequisites of a great throwing distance are more unfavourable for low-level than for top-level throwers. The reason for this is that because of high attitude angles, low-level throwers show higher angles of attack than top-level throwers.

Biomechanical factors of influence

Since dynamic features of the javelin-throwing movement can rarely be measured because of competition-organisational and investigation-economical reasons, we restrict ourselves to the presentation of kinematic factors which influence the release.

The achievement of a high velocity of release is dependent on the quality of the impulse transmission from the trunk to the missile via the throwing arm. The temporal coordination of the change of velocity (acceleration or deceleration) of the hip, shoulder, and elbow of the throwing-arm side is an indicator of the impulse transmission. Fig. 5 shows the features we examined in order to analyse the impulse transmission during the release phase.

By braking the individual segments and joint points, an impulse transmission to the neighbouring segment or segment chain is created. In this phase, the lower segments and joint points reach their maximum velocity earlier than the upper ones.

Of the investigated maximum velocities, the maximum velocity of the elbow v_{maxE} shows the closest correlation with the release velocity of the javelin ($r = 0.78$). A prerequisite of a high velocity of the elbow is an optimum impulse transmission from the lower extremities to the throwing arm. Factors of influence of the impulse transmission from the lower extremities to the throwing arm are the duration of acceleration t_{3H} and the reduction in the velocity of the hip Δv_H. Between the maximum velocity of the elbow v_{maxE} and the reduction in the velocity of the hip Δv_H there is a correlation of $r = 0.76$. There is a negative cor-

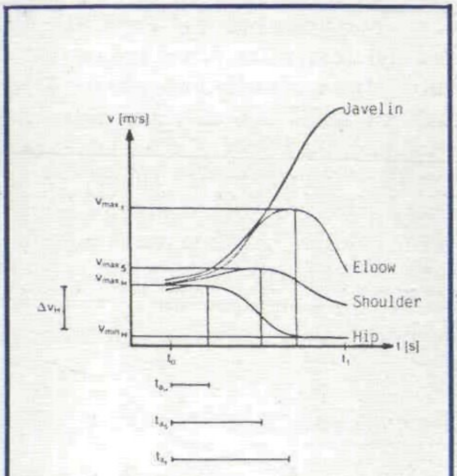

Fig. 5 - Indicators of the impulse transmission during the bracing phase

Key:

t_{aH} - Duration of the acceleration of the hip (throwing-arm side)

t_{aS} - Duration of the acceleration of the shoulder (throwing-arm side)

t_{aE} - Duration of the acceleration of the elbow (throwing-arm side)

v_{maxH} - Maximal velocity of the hip (throwing-arm side) during the bracing phase

v_{minH} - Minimal velocity of the hip (throwing-arm side) during the bracing phase

v_{maxS} - Maximal velocity of the shoulder (throwing-arm side) during the bracing phase

v_{maxE} - Maximal velocity of the elbow (throwing-arm side) during the bracing phase

t_o - Beginning of the two-legged support phase (bracing phase)

t_1 - Moment of release (end of the bracing phase)

Δv_H - Reduction of the velocity of the hip

relation between the reduction in the velocity of the hip and the duration of the velocity of the hip ($r = 0.68$), i.e., the reduction in the velocity of the hip is the higher, the earlier the velocity is reduced. An indicator of a fast and intensive braking movement is the magnitude of the knee angle of the bracing leg. The objective is the achievement of a knee angle varying between 160 and 180° (extension of the bracing leg) during the entire bracing phase. This makes possible an early and great reduction in the velocity of the lower extremities and the trunk. Table 9 gives information on the maximum velocity of the elbow v_{maxE}, the reduction in the velocity of the hip Δv_H, the duration of the acceleration of the hip t_{aH}, and the minimum knee angles of the bracing leg ε_{min}.

Training hints

With low-level athletes there is the tendency that the release direction (angle of release $\bar{\alpha}_o$) deviates too much from the javelin direction (angle of attitude β_o). This angle difference can generally be put down to the fact that low-level athletes show too steep angles of attitude. The angle of attitude should not deviate more than 8 degrees from the angle of release.

In order to achieve an optimum impulse transmission, the bracing leg is planted with a "gripping, striking" movement (*Bauersfeld/Schröter* 1980). This is the beginning of the bow-tension, which is released by straightening up the trunk over the bracing leg. The building-up of an optimum bow-tension is achieved by an optimum position of the body segments at the end of the release-preparatory phase (beginning of the one-legged support phase of the bracing stride) and an optimum length of the bracing stride. An optimum position of the body segments means an angle of inclination ε of the longitudinal axis of the body of approximately 30-35° in relation to the vertical line as well as a throwing arm which is extended as much as possible.

Less qualified throwers show a very short bracing stride, which results in a greater height of release (Table 10).

A too short bracing stride can lead to "running over" the bracing leg or to a strong rotation of the trunk around the bracing leg. In both cases, the approach velocity is not optimally used for the impulse transmission from the trunk to the throwing arm.

While in the first case the thrower keeps a high velocity in the direction of the approach even at the end of the release phase, there is in the second case a reduction of the velocity in the direction of the approach which is caused by the rotation around the longitudinal axis of the body. In many cases there can be at the same time an extreme bending of the body over the hip of the bracing leg. In both cases the rear foot breaks contact with the ground already before the moment of release.

The quality of the impulse transmission from the trunk to the throwing arm is dependent on the effect of the bracing action. Only if the bracing leg is extended during the whole release phase, an optimum reduction of the approach velocity can be achieved. The impulse transmission from the trunk to the throwing arm can be successfully aimed at via the knee angle of the bracing leg (required value range of the minimum knee angle of the bracing leg: 150-180°). If the action of the bracing leg is insufficient, the position of the body at the beginning of the release has to be checked together with the length of the bracing stride and the approach velocity.

4. Braking

Beginning: after the last contact of the hand with the javelin.

End: after considerable reduction of the approach velocity.

Objective: minimization of the braking distance, which is necessary for a further, complete deceleration after the release.

Biomechanical objective: length of the braking stride.

Comment:

In order not to foul the line, the approach velocity, which is reduced during the release phase only by 30-40°, has to be reduced to zero. The shorter the distance which is needed for the braking stride(s) (length of the final phase), the nearer can the place of release be to the foul line. Since the throwing distance is only measured up to the foul line and not up to the real place of release, it is useful that the distance between the place of release and the foul line (safe distance) is a short as possible (Table 11).

Table 9 - Mean competitive distance $\bar{W}$ and group mean values of the maximum velocity of the hip of the elbow $\bar{v}_{maxE}$, the reduction in the velocity of the hip $\Delta\bar{v}_{H}$, the duration of the acceleration of the hip $\bar{t}_{aH}$, as well as the minimum knee angle of the bracing leg $\bar{\varepsilon}_{min}$ of different groups of throwers (own investigation)

$\bar{W}$ [m]	$\bar{v}_{maxE}$ [m/s]	$\Delta\bar{v}_{H}$ [m/s]	$\bar{t}_{aH}$ [s]	$\bar{\varepsilon}_{min}$ [°]	Group of throwers
56.32	12.7	3.8	0.02	148	Female specialists
36.82	12.0	3.1	0.04	134	Pentathletes
74.64	15.3	4.3	0.01	156	Male specialists
53.60	12.7	3.1	0.04	137	Decathletes

Table 10 - Mean competitive throwing distance $\bar{W}$, group mean values of the release height $\bar{h}_o$ and the length of the bracing stride $\bar{l}_o$ of different groups of throwers (own investigation)

$\bar{W}$ [m]	$\bar{h}_o$ [m]	$\bar{l}_o$ [m]	Group of throwers
56.32	1.65	1.47	Female specialists
36.82	1.83	1.26	Pentathletes
74.64	1.80	1.56	Male specialists
53.60	1.96	1.32	Decathletes

Table 11 - Mean competitive throwing distance $\bar{W}$, group mean values of the length of the end phase $\bar{d}_1$ and safe distance $\bar{d}_2$ of different groups of throwers (own investigation)

$\bar{W}$ [m]	$\bar{d}_1$ [m]	$\bar{d}_2$ [m]	Group of throwers
56.32	1.22	0.78	Female specialists
36.82	1.10	0.82	Pentathletes
74.64	1.51	1.13	Male specialists
53.60	1.20	0.68	Decathletes

Biomechanical factors of influence

1. Velocity of the centre of gravity (CG) at the end of the release phase.

2. Position of the segments of the body at the end of the release phase.

Comment:

The length of the final phase can be successfully minimized if the velocity of the CG is already considerably reduced during the release phase, and if the position of the body segments after the release permits a reduction of the remaining approach velocity by a braking stride which does not throw the athlete off balance. Low-level throwers often need more than one braking stride or a few hops, whereas high-level throwers are able to completely reduce their remaining horizontal velocity by a single braking stride.

Although the specialists reduce their approach velocity during the bracing phase to a higher extent than low-level throwers, their CG-velocities at the moment of release are still slightly higher. This could be a reason for the fact that the average length of the final phase of the specialists is not much greater than the one of multiple-event athletes (Table 12).

Training hints

Since the length of the final phase is determined by the approach velocity and its reduction during the release phase, the training hints given for the release also apply to the regulation of the length of the final phase (see chapter 3).

5. Flight of the javelin

Beginning: after the last contact of the hand with the javelin.

End: first contact of the javelin with the ground.

Comment:

As compared to the other movement phases of javelin throwing, the flight is a special case since it only concerns the javelin, and the athlete cannot further influence the movement of the javelin. Therefore we want to inform about those aerodynamic factors influencing the flight of the javelin which cannot be directly controlled by the thrower. As far as the flight behaviour of the javelin is concerned, there are considerable deficiencies in research because of difficulties in measuring methods. That is why predominantly only qualitative statements can be made.

Influence factors of the javelin flight

Because of the differences between the velocity of the javelin and the velocity of the wind, aerodynamic forces appear which operate on the centre of pressure (CP) of the javelin. The CP is not identical with the CG of the javelin (Fig. 6).

Table 12 - Mean competitive throwing distance $\bar{W}$, group mean values of the absolute (Δv_{CG} [m/s]) and the relative (Δv_{CG} [%]) velocity reduction of the CG and the CG-velocity at the moment of release ($\bar{v}_{CG}$; own investigation)

$\Delta\bar{v}_{CG}$ [m/s]	$\Delta\bar{v}_{CG}$ [%]	$\bar{v}_{CG}$ [m/s]	Group of throwers
2.5	43	3.3	Male specialists
1.6	35	3.0	Decathletes

Because of the different positions of the CP and the CG, a pitching moment is created (PM), which turns the nose of the javelin down.
The greater the PM, the greater is the distance between the CG and the CP (Δl). With throws of shorter distances, the nose of the javelin must dive down faster than with throws of greater distances. The reason for this is the shorter duration of the flight. Therefore, javelins for different ranges of distance are built with different pitching moments. The CP of men's longer-distance rated javelins (70 to 90 m) is only 1 to 2 cm behind the CG; this distance is greater on short-distance rated javelins (Δl). The aerodynamic forces operating on the javelin are the drag and the lift. The drag force operates

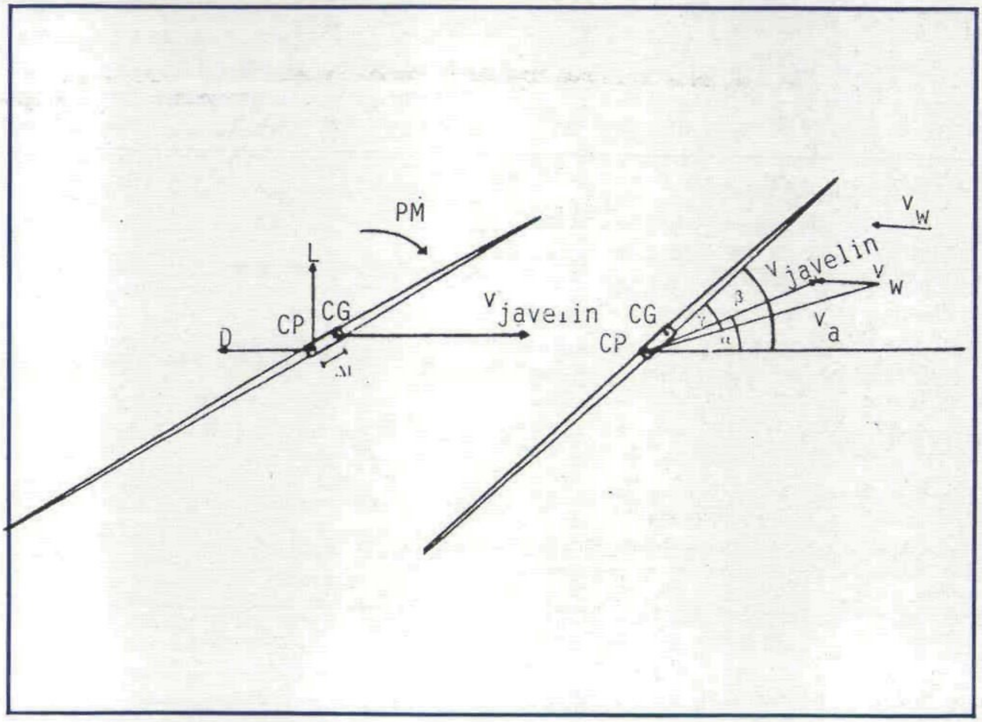

Fig. 6 - Aerodynamic factors influencing the flight of the javelin

Key:

CG - Centre of Gravity
CP - Centre of pressure
L - Lift
D - Drag
PM - Pitching moment
Δl - Distance between CG and CP

v_w - Absolute velocity of the wind
$v_{Javelin}$ - Absolute velocity of the javelin
v_a - Velocity of air flow
α - Angle of release
β - Angle of attitude
γ - Angle of air flow

against the direction of flight, whereas the lift force operates vertically to the direction of flight. The relationship between lift and drag is dependent on the angle of air flow, which on its part is dependent on the attitude angle of the javelin, the flight direction, and the wind direction (fig. 6).

According to investigations by *Terauds* (1974) on different javelins, drag and lift are identical if the angle of air flows is between 42 and 46°; the lift-drag ratio is most favourable at angles of air flow between 10 and 16°. On the basis of these investigation results, the demand for an angle of air flow between 10 and 16° can be deduced. This must be qualified by saying that rotations and vibrations of the javelin are not taken into account.

Since tail- and headwind change the height as well as the direction of the velocity of air flow, the angles of release and of attitude have to be suited to these variable conditions in order to attain the above mentioned optimal angle of air-flow (10-16°).

From theoretical and empirical investigations, *Tutjowitsch* (1976) in accordance with *Terauds* (1978) deduces that, as far as the practice of training is concerned, the optimum angles of release increase together with the increasing velocity of release.

Besides, *Tutjowitsch* comes to the conclusion that the increase in throwing distance caused by tailwind is greater than the reduction in throwing distance caused by an equally strong headwind. In case of head- and tailwind, *Tutjowitsch* recommends a negative angle of attack τ_o (i.e., the angle of release α_o is greater than the angle of attitude β_o) with an angle of release which is 2 degrees higher in case of tailwind than in case of no wind at all.

□

(Readers will realize that the fligth characteristics here described refer to the old specification men's javelin and to current women's models. For the characteristics of the new javelin, please refer to the article by W. Paish on pages 81-84).

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