

## **Model technique analysis sheets for the vertical jumps – The Pole Vault**

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### **Introduction**

The pole vault is the only athletic event in which the performance measured is produced with the aid of an implement. Correspondingly, performance development in this event is dependent on the development of vaulting poles. Since the middle of the last century, various materials have been used for pole construction: wood, iron, bamboo, aluminium, steel, fibreglass and, most recently, carbon fibre. The rules are, of course, open to further development, with the only requirement being that all competitors be given enough time to test new poles before their use in international championships. If one considers that the sense of all record lists depends on the constancy of conditions, the “liberality” demonstrated by the IAAF with regard to this event is remarkable. In any case it was logically consistent to start the lists again in 1961 when fibreglass poles were officially accepted by the IAAF. Until then it had been quite normal that in the same competition poles of different materials were used. This abruptly changed when some athletes were able to utilize the elastic characteristics hidden in synthetic poles, that had already been used by some athletes from 1956 onward.

These advantages can only be utilized if the athlete employs a special movement technique. A flexible pole can only “refund” energy that has been previously “invested” in it. In fact, in the case of world class pole vaulters, this energy balance is positive. In other words, the athlete's mechanical work on the pole after the take-off creates extra lift (cf. GROS/TERAUDS 1983). The achievement of this places extremely complex demands on both the athlete's physical-motor and technical-motor abilities, making pole vaulting a combination of athletic and gymnastic elements.

In the following, an attempt is made to present the phase structure of modern vaulting technique and to explain important elements of the phases. The objective is to construct a “model of pole vaulting technique” (cf. TIDOW 1981).

To begin with, a principal factor to consider is that vaulting rhythm changes in a direct relationship to grip height. The vaulting rhythm directly influences the execution and duration of the movement phases, as well as the total duration of the vault (cf. JAGODIN et al. 1979). Therefore, any model must be limited in its applicability in accordance with this time constraint. In the case of the model presented here, for performances between 5.50 and 6m, 1,300 msec are required from take-off to bar clearance. An impression of the total process of such a vault is given in *Figure 1*. In order to demonstrate the bending behaviour and avoid the overlapping of certain figures, the individual pictures have been slightly stretched out horizontally.

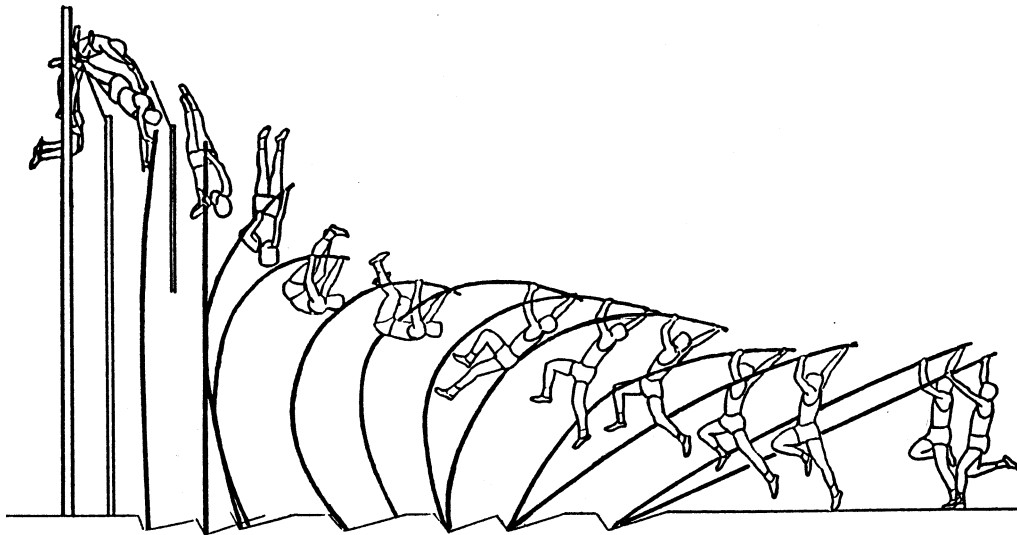


Figure 1: Target pole vault technique (Sergey Bubka (URS), height: 5.85m). In this attempt, the position of the uprights is not ideal. However, the graphic presentation of the movement sequence has not been changed.

## The run-up

The pole vault run-up is usually slightly shorter than the run-up in the long jump, consisting of 18 to 20 steps. Performance in the pole vault is influenced by the height of the athlete's grip on the pole, the firmness of the pole and run-up velocity. In the case of world class vaulters, the pole firmness is 20kg higher than body weight and the grip height is 5.20m. Such a high grip height decreases the angle of the pole at plant, thereby increasing the angular rotation required for the pole to reach vertical. Therefore, maximum velocity on the run-up is essential. Measurements of the run-up velocity during the penultimate stride of world class vaulters have shown velocities between 9.3 and 9.7m/sec (cf. GROS/TERAUDS 1983; JAGODIN 1982; MANSVETOV 1983).

In some vaulters, the difference between maximal sprint performance and pole vault run-up velocity is less than 1m/sec (cf. MALJUTIN 1979). This is remarkable since the vaulter, carrying a 5m pole weighing 4 to 5kg, must perform a controlled plant and hit the optimal take-off point precisely. Such a small differential in run-up velocity is the result of two factors:

1. Target-oriented training e.g. sprints with weighted poles, filled with concrete, lead balls or other material.
2. A "special" pole carry.

Experiments in the USSR (see MALJUTIN 1979; MALJUTIN 1974) prove that the type of pole carry has a great influence on the individual athlete's maximal run-up velocity. The special pole carry is characterized by a vertical alignment of the longitudinal axis of the pole which is the result of significantly raising the tip. A considerably higher velocity can be achieved with this carry than with the pole carried horizontally. Since the pole must be lowered for the plant and any abrupt, hasty changes of pole position would have a negative influence on the velocity curve, PETROV has made a virtue out of a necessity (cf. PETROV 1985). He recommends starting with the pole at an angle of 70° (see Figure 2) and then to lowering it smoothly as the run-up progresses.

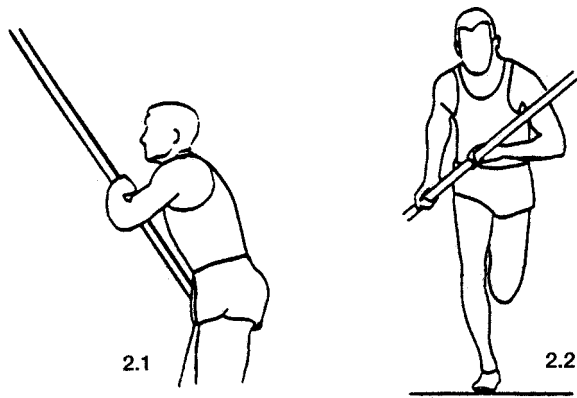


Figure 2: Type of pole carry at the start (left) and during the run-up

The “pulling force” which the pole exerts on the vaulter during the process of lowering the pole in the run-up is caused by the centre of gravity (CG) of the pole moving further and further away from the vaulter. This can be positively integrated into the acceleration action if the velocity of pole lowering is coordinated with the run-up velocity. It is especially important that the vaulter remains erect, particularly during the second section of the run-up by keeping his hips high, with the emphasis on stride frequency (see Figure 3).

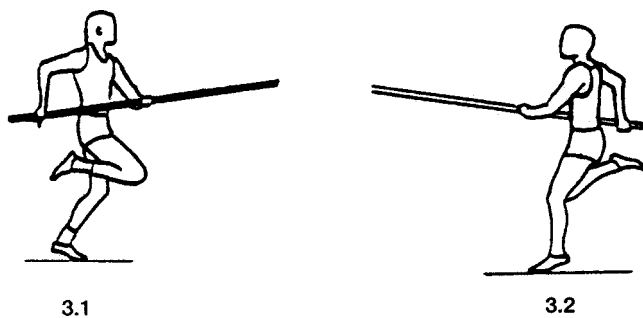


Figure 3: Run on the balls of the feet with emphasis on high frequency, “high” hips, frontally aligned trunk and bent arms

In this way, the de-stabilizing influence of the lowered pole on the vaulter’s lateral axis, particularly during the flight phases, can be reduced. Furthermore, sprinting with the emphasis on stride frequency produces a “high-level” movement of the CG, parallel to the ground with minimal deviations. This contributes to a run-up free of disturbances and prepares for a “high plant”.

If one follows PETROV’s previously mentioned opinion, the run-up leads directly to the take-off. The dynamic process of pole lowering, which must be performed during the run-up, is only finished when the bottom end of the pole touches the metal plate of the vaulting box. For didactical reasons, however, the plant preparation and the plant itself will be discussed separately, before dealing with the take-off.

### Plant preparation and plant

The debate on when the vaulter should initiate preparation for the pole plant during the last two or last three run-up steps continues. From the point of view of movement flow, there are some reasons for initiating the plant preparation during the third to last step (see Figure 4).

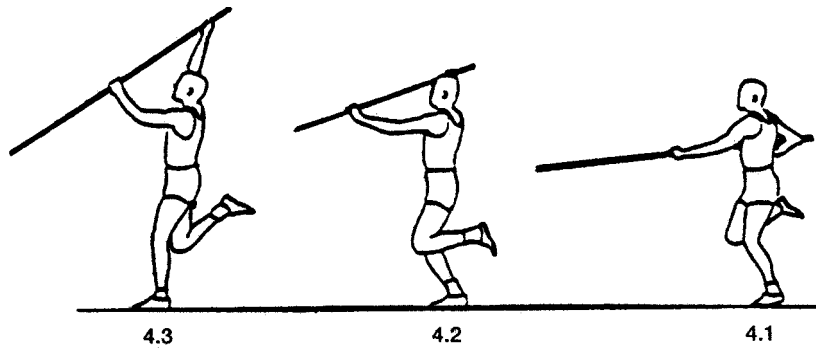


Figure 4: Plant preparation over three steps. During the third to last step the pole has been moved close to the trunk so that the top hand is above the hip when the third to last foot contact takes place (see Figure 4.1)

During the penultimate stride, the tip of the pole can be lowered further from the horizontal position, and its end can be moved to the front and above. In the case of the two-step plant rhythm (see Figure 5) this pole movement takes place during the penultimate step. The only difference, therefore, is the horizontal shifting of the pole to the front during the third to last step for the three-step variation.

This shift to the front, however, leads to a moving away of the pole's CG from the vaulter's CG exactly at the moment when the pole exerts maximal "load" because of its horizontal alignment. According to current knowledge, none of these variations can be regarded as optimal. If, however, one observes the movement behaviour of the world's best pole vaulters, it becomes obvious that the two-step variation occurs significantly more often. This is possibly connected with the increasingly longer poles and higher grips with a relatively close handsread. In other words, in the case of a grip height of 5.15m and a handsread of at least 50cm, the energy expenditure needed for the stabilization of the complete system during the "three-step-variation" is so high that its original advantage, the smooth bringing forward of the pole, is negated.

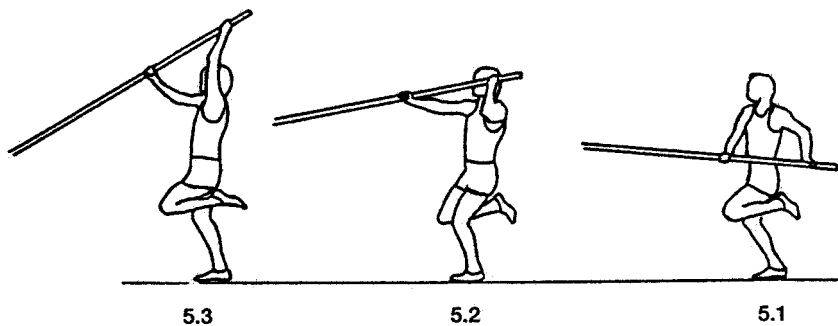
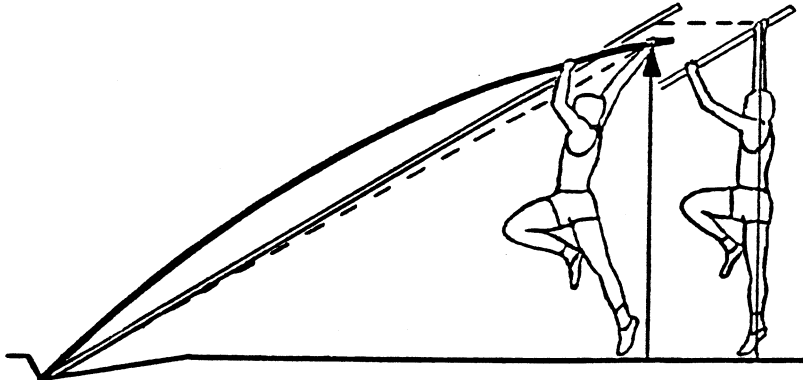


Figure 5: Plant preparation over two steps. The pole covers a longer distance between the third to last and the penultimate ground contacts, i.e. during the penultimate step, since it is brought directly forward from the "normal" run-up position (compare Figure 5.1 with Figure 5.2).

As already mentioned briefly, the vaulter's position during the penultimate contact (support on the swing leg) should be congruent, regardless of the planting rhythm chosen. The top arm is bent and has lifted the end of the pole to approximately head height. The lower arm is horizontally extended, supporting the pole and controlling its lowering velocity during the target-directed plant. The trunk is straight or is inclined slightly backwards. In this phase, most vaulters exhibit a flat touchdown of the respective foot, with the support leg being slightly bent, so that the result is a "high" squat position on the swing leg (see Figures 4.3 and 5.2).

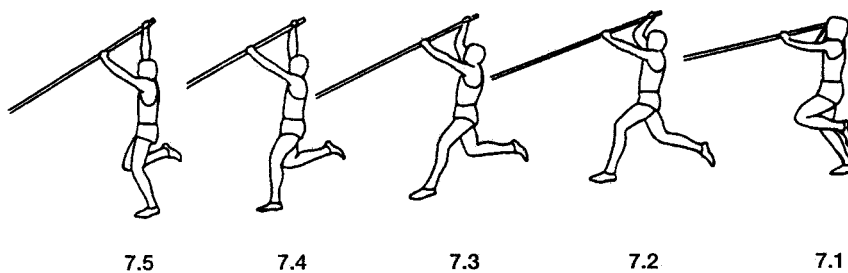
## Plant and take-off

To minimize energy transmission losses, pole plant and take-off must form a movement unit. This goal can only be achieved if the point of take-off, geometrically determined by the height of the grip, is hit as exactly as possible. This means that the take-off foot must be perpendicularly under the top hand, and the vaulter must completely utilize his maximally extended reach (see *Figure 6*).



*Figure 6: Comparison between the dynamic and static plant angle. Because of the take-off dynamics and the fixed top hand, the static plant height is necessarily reduced. If one shifts the Figure on the right to left, it becomes obvious that the dynamic and static points of take-off are almost identical (Figure according to TIDOW 1989)*

During the take-off step, which is performed fast and actively with the ball of the leading foot, the top end of the pole is pushed vertically upwards by the top arm. Since the handsread is comparatively close (50 to 60cm), the extended lower arm participates in this upward movement of target-directed positioning of the pole. When the front support, with the hips remaining “high”, has been achieved, both arms are *extended* and tensed (see *Figure 7, phases 7.4 and 7.5*).



*Figure 7: Take-off step and pole plant in five phases (7.1 to 7.5)*

When the top arm and trunk are vertically aligned, the vaulter's CG moves past the take-off point (see *phase 7.5*). The fact that the pole is not yet moved to the side indicates that the tip of the pole has not yet touched the back of the vaulting box. This is a description of the “free take-off” postulated by PETROV (cf. PETROV 1985). Contrary to steel pole technique, as well as the conception of many fibreglass vaulters, the pole and the vaulter maintain their maximum velocity until the tip of the pole hits the back of the box.

If the take-off is performed towards the front and upwards, with the vaulter extending *upwards* (in order to maximize the plant angle) and actively moving towards *the front* (in order to induce “penetration”), the result is a “take-off figure” that in modern pole vault is largely standardized (see *Figure 8, phase 8.3*).

If one compares *phases 8.1 and 8.4*, it becomes obvious that the almost vertical alignment between the top hand and the take-off foot is maintained although the vaulter's CG is considerably shifted towards the box.

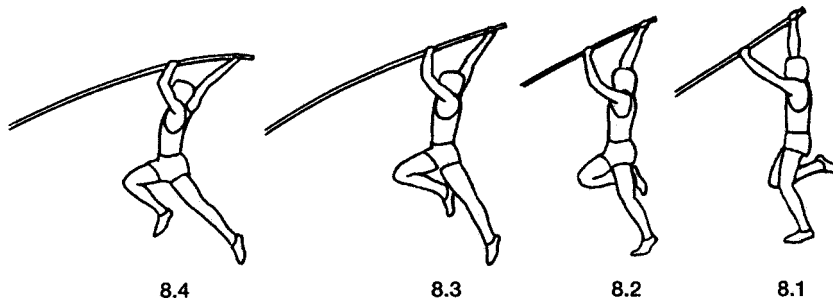


Figure 8: Pole vault take-off in four phases (8.1 to 8.4)

This forward movement of the trunk is only possible because the passive elasticity of the pre-tensed arm and shoulder muscles allow a comparatively "smooth" compensatory movement. The trunk is rigid, and the shoulder axis is frontally aligned as exactly as possible, with the right shoulder joint and the left elbow joint "compulsorily flexed" to the take-off direction. Correspondingly, the head of the vaulter pushing towards the front is shifted from its initial position below the top arm (*phase 8.1*) towards the lower hand (*phase 8.4* = "penetration posture"). During this process, the hips do not yet swing forward.

Despite most vaulters exhibiting an almost extended lower arm and locked elbow joint, the athlete does not take off "against" the pole locked in the box, but more or less together with it. From this movement behaviour at least two advantages can be derived:

1. The transmission losses are reduced to a minimum.
2. The relatively narrow grip required for this movement is an optimal prerequisite to the efficient use of both arms in the following pull, turn and push phase.

A short noise produced by the pad at the tip of the pole when it hits the back of the box always signals the "free take-off" when it does not precede the take-off. This can be heard immediately after the contact of the take-off foot.

It should also be mentioned that the take-off posture in the pole vault, in comparison with the long jump, is characterized by a lower knee lift and a significantly more acute knee joint angle of the swing leg. This is a sign of the athlete striving for a primarily horizontal penetration with a vertically lifted CG. The widely expressed opinion that the take-off should be directed "upwards" cannot be recommended. The "tip-take-off" striven for by some vaulters, characterized by a push-off which is similar to a hurdler's, i.e. from the ball of the foot without touching the ground with the heel, has a different objective. As far as physics is concerned, the vaulter should try to maximize the penetration impulse during the take-off. By doing so he succeeds in converting kinetic to potential energy and thereby shortening the "true axis of the pole" (cf. GANSLEN 1968), that is, the radius within which the whole system rotates. So, at the moment of maximum bend, the length of the chord of the pole curve is only 70% of the resting length of the pole (cf. ALLMANN 1983; GEESE/WOZNICK 1980).

This short-time, with the dynamic shortening of the pole and corresponding "stored" reversible force, is the primary reason for the fact that the grip heights of today's top pole vaulters have been increased by more than 1m since the steel pole era (see HOUVION 1982).

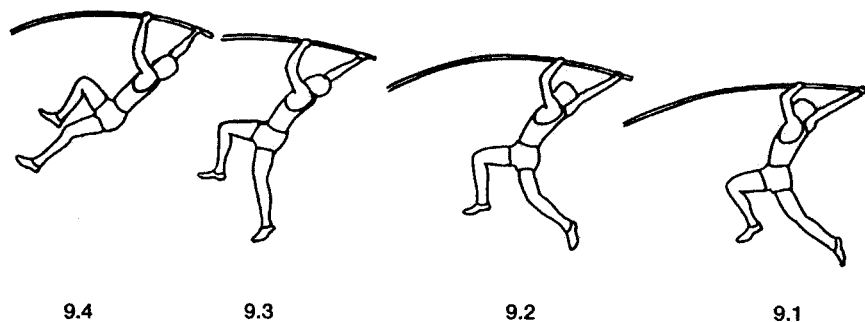
On the other hand, the penetration angle, which should be as large as possible, is achieved through the extension of the whole body and a high lift of the top arm and shoulder. Provided there is enough kinetic energy in relation to the grip height chosen and that the take-off point has been hit exactly, the system “automatically” straightens. *During this movement, the pole, not the take-off leg, serves as a lever.* If one considers this aspect, the question arises whether the movement affinity between long jump and pole vault, postulated on the basis of almost identical take-off angles, really exists.

Strictly speaking, even the term “fly off” angle is misleading with regard to the pole vault, since, even after the take-off, the vaulter has contact with the ground via the pole, which is by no means without effects. The kinetic and mechanical contributions to the “product” *swing-off* angle must be interpreted differently from those determining the fly-off angle in the long jump.

An upward take-off impulse would be quickly overcome by gravitational forces coming into play, disturbing optimal bending dynamics. In the case of a primarily vertical push-off, a smooth transition to the long pendulum would be impossible. So nobody doing a long swing on the rings or rope would hit on the idea of springing off from the ground. Thus, the take-off in the pole vault should not, as is common practice, be called “similar to the long jump”, but “similar to the triple jump” at best (cf. KRESINSKI 1979). Even this comparison is restricted by the validity of such analogies.

### Pole penetration and upswing

The penetration phase, which is introduced with the take-off, continues until the “penetration energy” resulting from the take-off impulse is virtually used up (cf. CZINGON/KRUBER 1981). The trunk is rigid and frontal, with over-extension of the hip joint on the side of the extended take-off leg. Immediately after the take-off, the vaulter behaves rather passively and preserves his “penetration position” (see *Figure 9*) in order to let the “take-off impulse” work.



*Figure 9: Penetration into the pole until pendulum transition*

The upswing commences only when the trunk is again aligned with the top arm, or the over-extension in the shoulder joint, which must exhibit a high passive flexibility, is released again. The upswing leads from the long hang position of the “pendulum transition” (see *phase 9.4* and *Figure 10*) via a roll upwards and backwards “rock-back” to the “stretched inverted hang”, which is also called the “*l-position*”. Since the extended take-off leg has been held back deliberately, it can now take on its swinging function, starting from an optimal pre-stretch of the muscles. In doing so, it remains extended. The transition from the long to the short pendulum takes place when, during the long swing, the vaulter’s horizontal axis moves past the chord parallel with the pole curvature (see *Figure 10*).

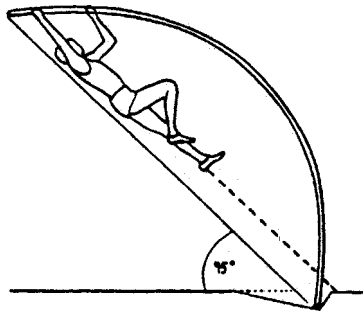


Figure 10: Pendulum transition. This phase is reached when the longitudinal axis of the body is in a 45° position. The lower arm should already be “somewhat extended”.

The pole “reacts” to this upward, rolling movement, which primarily rotates about the shoulder axis, by bending even further. Maximal bending is achieved when the vaulter’s back is almost parallel with the ground. According to KRESINSKI, maximal bending has been achieved when the vaulter’s trunk is parallel with the upper end of the pole above him.

When the maximum pole bend phase has been achieved, the vaulter is approaching the “L-position”. This position signals that the “process of charging” the pole with an impulse effect, which is primarily directed horizontally and diagonally toward the landing cushion, is finished (see Figure 11). The subsequent upward movement must be performed synchronously with the straightening of the pole.

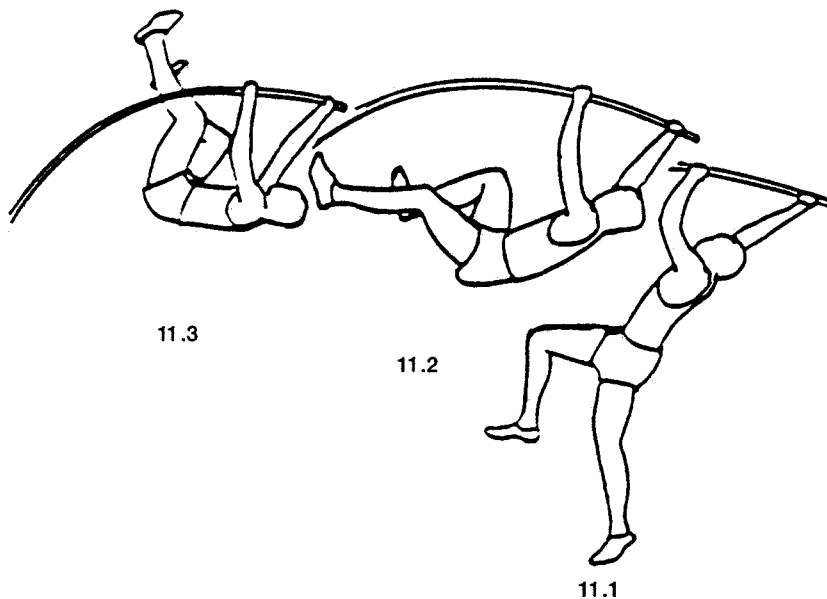


Figure 11: From the beginning of the upswing to the L-position with maximum pole bend

The skill of the pole vaulter relies on his ability to let the rolling upward action (see Figure 11.1 to 11.3), which is performed with a great moment of mass inertia and an extended or extending (lower) arm, translate to a backward roll by flexing his hips and finishing the following upward movement in such a way that his pelvis comes close to his top hand. This is achieved through an active extension of the hips and trunk, the top arm remaining extended (see Figure 12).

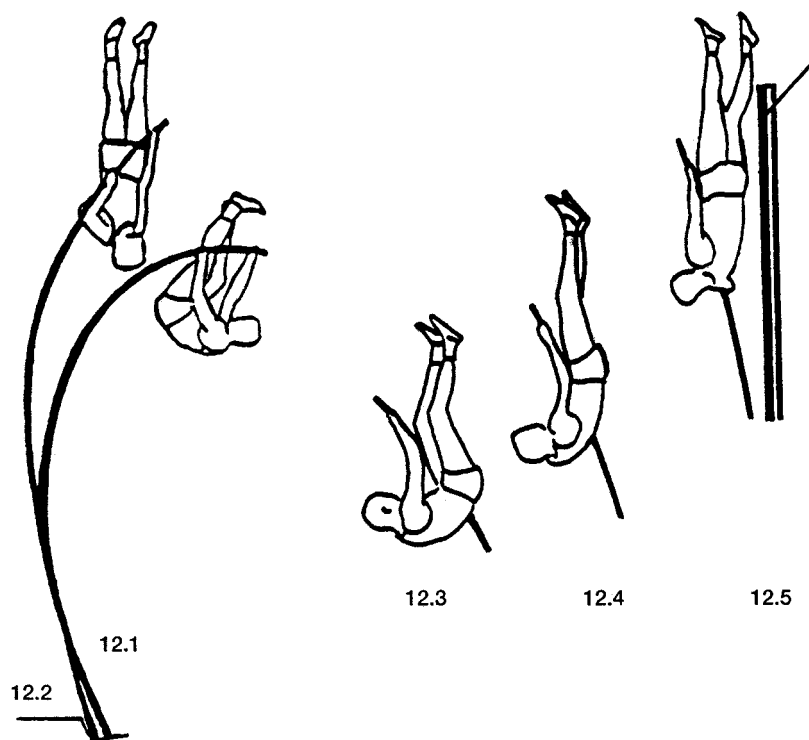


Figure 12: From the "L-phase" to the "stretched inverted hang" ("I-position"). Left side: starting and final position including bending of the pole; right side: from a different point of view and including the "J-phase"

These actions have a mechanical effect on the pole. After having achieved the "L-position", the pole does not bend further because in this phase its straightening force is already greater than the "pressure" exerted on it by the athlete rolling backward and thrusting his hips and legs upward. Therefore, the "gymnastics on the pole" have only a delaying influence on the pole's straightening. If the extension of the vaulter's whole body in the inverted hang is achieved before the straightening of the pole, the remaining straightening energy or the resulting catapult acceleration can be integrated into the final pull, turn and push action (see Figure 13). Two prerequisites of this are, however, that the vaulter tenses after having achieved the inverted hang, and that his trunk is still in front of the pole. If these two are not fulfilled, the vertical impulse of the pole cannot "hit" the vaulter optimally. The fact that the lower arm is closely fixed to the pole contributes to the controlled execution of this action of "tensing" (vertically), which even includes the ankles.

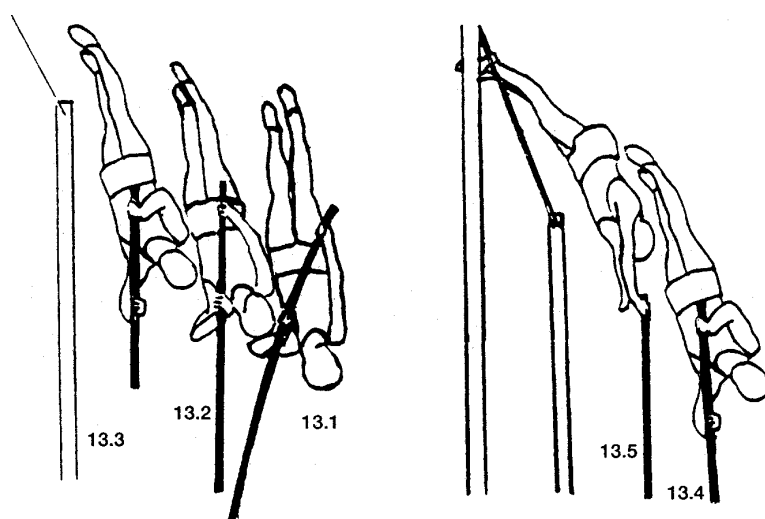


Figure 13: From the "lifted" stretched inverted hang to the turn and reverse (left) and from the turn and reverse to the push-off phase

When the stretched, inverted hang position has been achieved, the upswing on the pole is almost finished. The vaulter's shoulder axis, and his CG, should continue to rise, his top arm remaining extended. In doing so, the vaulter's lower arm, which is close to the inner side of the pole, flexes at the elbow joint and wrist until the shoulder on the same side reaches the lower hand. In other words, the "I-position" is preserved until this vertical shift of the vaulter has taken place (compare *Figure 12* with *Figure 13*).

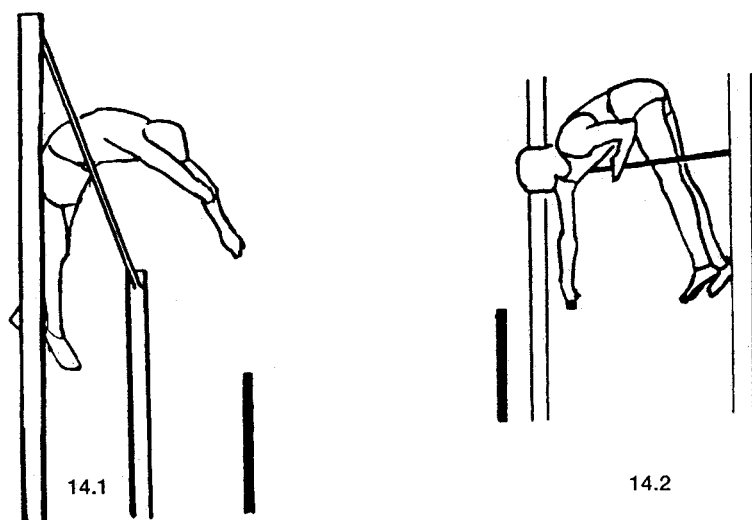
### **Pull, turn and push and bar clearance**

If the vaulter has managed to reach the continuous, quasi "lifted" "I-position" synchronously with the recoil of the pole, but before its complete straightening, the pull-support phase, which must be performed against gravity, is considerably easier. Only at this point is the top arm flexed. In doing so, the athlete should imagine pushing the pole deep into the vaulting box with both arms. The asymmetry of the body's "suspension" on the hands' staggered grasp of the pole causes the vaulter to rotate about his body's longitudinal axis.

This rotational movement is initiated from a 90° position of the vaulter to the pole. This position has already been assumed in the "lifted" inverted hang phase (see *Figure 13*). The rotational movement is first effected in the leg-hips section, which is still "rigid", and then the trunk.

During this rotational movement, the right shoulder is brought close to the pole, primarily through the pulling action of the top arm, so that the flexed top arm can give a residual impulse to the upwardly accelerated body by performing a downwardly pushing extension on the pole. This push-off movement with a rising trunk results in first the lower and the top hand releasing the pole (see *Figure 13*).

The bar clearance phase is optimal if, in the culminating point of the trajectory immediately above the crossbar, the vaulter succeeds in creating a horse-shoe shaped whole-body arch or a "V" by the fast flexion of his hips and lowering of his head (chin to chest) (see *Figure 14*).



*Figure 14: Bar clearance in the form of a horse-shoe or "V"*

At the moment of bar clearance there is, simultaneously, mass on both sides of the crossbar. The posture eventually chosen depends, among other things, on the vaulter's actual position in relation to the crossbar or the uprights.

Since the restoring energy and particularly the "discharge direction" cannot be standardized, even in the case of a constant grip (because the discharge direction is the "response" to the athlete's variable movement behaviour), the optimal adjustment of the uprights remains a risk. Consequently, in the case of a sufficiently high vault where the high point of the trajectory of the CG is not vertically-above the crossbar, the athlete's skill determines clearance of the bar.

A slightly scissoring leg movement during the push-off phase, with the right leg being moved slightly towards the front and the left leg being correspondingly moved backwards, seems to be quite sensible. With such a movement during the diagonally upward directed “flight toward the crossbar”, the vaulter can possibly succeed in removing his left leg, which is close to the bar, out of danger. A stronger scissoring movement should, however, be avoided because it would lead to an increase in the mass inertia moment. This would make the rotation of the body's longitudinal axis during the turn and reverse more difficult.

Furthermore, the rotation impulse about the lateral axis, which often varies although it should be kept as low as possible, might influence the type of bar clearance. Bar clearance in the form of a “V” presumably requires a higher impulse about the lateral axis than the U-shape.

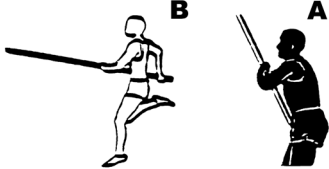
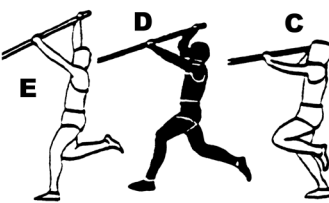
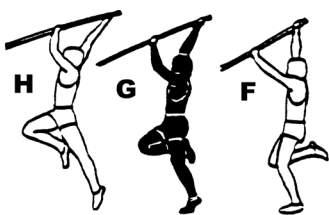
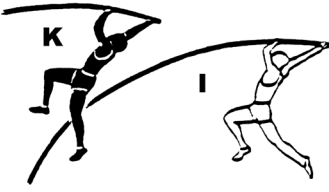
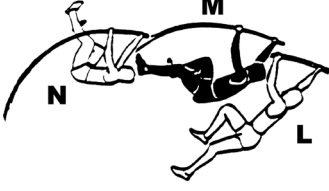

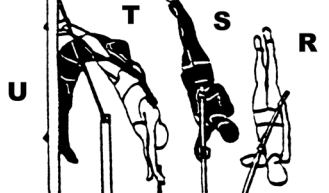
The fact that generally a 60cm stagger of the uprights is chosen proves that, with regard to the flight toward the crossbar, the pole vault is not finished by an exactly vertical movement, but that it contains a diagonal component, which is, however, extremely steeply directed upward.

Through working on the pole, the optimal utilization of the “recoil energy” of the pole and skillful positioning during the bar clearance phase, today's top pole vaulters have managed to increase the difference between grip height and the height cleared to up to 1.20m.

## Summary

The phases presented are integrated into the Pole Vault Analysis Sheet. In order to save space, the pole has not been shown in full. The reader, therefore, is recommended to go back to *Figure 1* (or the respective section) in order to clearly identify or evaluate the respective position or “figure” (including the corresponding degree of pole bend) within the whole movement sequence. It might then be possible to evaluate the movement partially – not only as far as space is concerned, but also with regard to time.

In the “reference” column, important points of observation of the respective movement phases, as phase elements, are identified. The corresponding requirements of movement characteristics are presented in the “criterion” column. For reasons of space, the “evaluation” column has only been indicated. A “+”, “0” or “-” symbol can be filled in, indicating that the corresponding criterion of the movement observed is “correct” (or “fulfilled”), “partially correct” (or “partially fulfilled”) or “not correct” (or “not fulfilled”). Using video systems, such a procedure can be valuable for evaluating phases or phase elements.

POLE VAULT	Phase	REFERENCE	CRITERION	ASSESSMENT	+	0	-
	Run-up	A 1 Carry A 2 Arm posture A 3 Lowering B 4 Trunk B 5 Pattern/rhythm B 6 Arms	At the beginning: steep/close to trunk/ Handspread ≈ 55 cm Top arm: flexed/hand in front of chest Smooth until plant Frontal/erect/still Emphasis on frequency/tall Flexed/still				
	Plant preparation:  Last stride	C 7 Top arm C 8 Lower arm C 9 Foot plant C-E 10 Top arm D 11 Take-off leg E 12 Arms E 13 Trunk/hips	Bent: at shoulder height/hand: at parting height Extended/horizontal/supports pole Flat Vertical extension movement Lead of the ball of the foot/no bracing Extended/in plant position/tensed Slight backward lean/'high'				
	Plant  ↓ Take-off	F 14 Medium support F 15 Body F 16 Arms G 17 Take-off foot G 18 Pole G-H 19 Body G-H 20 Trunk G-H 21 Arms H 22 Swing leg/heel	'free' (pole tip without contact) Erect/exactly below pole Top arm: vertically extended/lower arm: long Perpendicularly below top hand Beginning of bending Maximization of reaching height Frontal penetration/rigid Passive springing back/under pole axis Bent/foot: close to take-off thigh				
	Penetration maximum  ↓ Upswing (beginning)	I 23 Head I 24 Top arm I 25 Swing leg I 26 Take-off leg K 27 Take-off leg K 28 Swing leg K 29 Lower arm	Close to elbow bend of lower arm Extended/retroverted Flexed/thigh: locked in take-off position Locked in overextended hip position/long Takes over swing function/long Flexed/passive/'held' Extending abutment function				
	Pendulum transition  ↓ Maximum bend	L 30 Longitudinal axis L 31 Top arm L 32 Lower arm L 33 Rotation axis M 34 Hips N 35 Back N 36 Arms	Parallel with cord of pole curvature Extended 'abutment function' Shoulder joint Increased bending Parallel with ground Top arm: extended/lower arm 'long'				
	L-Phase  ↓ I-Phase	O 37 Top arm O 38 Feet O 39 Legs O 40 Pelvis Q 41 Top arm Q 42 Body Q 43 Lower arm	Extended Vertically above head & top hand Parallel/extended 'rising'/hip angle opens actively Still extended Vertical/extended/rigid/ turned toward pole Flexed/forearm. In contact with inside of pole				
	Inverted hang  ↓ Pull-turn  ↓ Push-off  ↓ Bar clearance	R 44 Top arm R 45 Lower arm S 46 Arms S 47 Body T 48 Flight toward crossbar U 49 Body U 50 Culmination point	Long Extremely flexed/upper arm: parallel with shoulder Active pull-support movement Rigid/turning/rising steeply Face down/rising steeply (≥ 150°) Horse-shoe or V-shape Vertically above bar level				

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