Standard Theory Of High Jump ver.1.0.1

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Contents

Chapter

1

The outline of high jump

1.1 Standard theory of high jump

The high jump can be roughly divided into three elements of "runup", "take off", and "clearance". Basic theory of high jump is summarized in the following elements.

- Runup
  ① Keep the center of gravity low at constant height, and run fast.
  ② Make moderate inward tilting posture at curved approach and backward tilted posture at take off fhase.

- Take off
  ③ Make the body like a straight rod at touchdown and lift the body straight up at take off
  ④ Take off in a short time
  ⑤ Increase the distance of take off as the athlete jump higher

- Clearance
  ⑥ Adjust inward tilting posture, backward tilted posture, and leading leg motion to make efficient clearance rotation
  ⑦ Control the head position, knee positions, and arch to adjust posture in the air as not to touch the bar

Figure 1.1: Basic theory of high jump

1.2 Rules for high jump

High jump is a competition where people compete for jumping height

The IAAF web site shows the rule of high jump as follows

> Competitors jump unaided and take off from one foot over a four-metre long horizontal bar. They seek to clear the greatest height without knocking the bar to the ground.
>
> All competitors have three attempts per height, although they can elect to "pass", i.e. advance to a greater height despite not having cleared the current one. Three consecutive failures at the same height, or combination of heights, cause a competitor's elimination.
>
> If competitors are tied on the same height, the winner will have had the fewest failures at that height. If competitors are still tied, the winner will have had the fewest failures across the entire competition. Thereafter, a jump-off will decide the winner.

Please see official documents published on the IAAF web site, if you want to know more details of rules.

1.3 History of high jump

It is very meaningful to know how fosbury flop was born through what kind of technical change in the past.

High jump clearance was historically changed to

- Lift the center of gravity as high as possible
- Make a posture that will not touch the bar as much as possible at the highest point

And finally fosbury flop was born

In the late eighteenth century simple techniques were used that bend the knees and jump. This clearance style is shown at the Fig.1.2 and can jump only h2 height (higher than h1).

The next technique was called "scissors". The legs are lifted over the bar in alternation one after the other. This technique can increase the height of the pelvis because the large part of lower body is below the bar height at the peak of jump. The scissors is shown at the Fig.1.2 and can jump h3 height (higher than h2). The scissors was used at least in 1874.

The scissors was flowed by the "eastern cut-off". The eastern cut-off was used at least in 1892. The athlete rotates the trunk into horizontal position at the peak of the jump. This method can lift the pelvis higher than scissors. The eastern cut-off is shown at the Fig.1.2 and can jump h4 height (higher than h3).

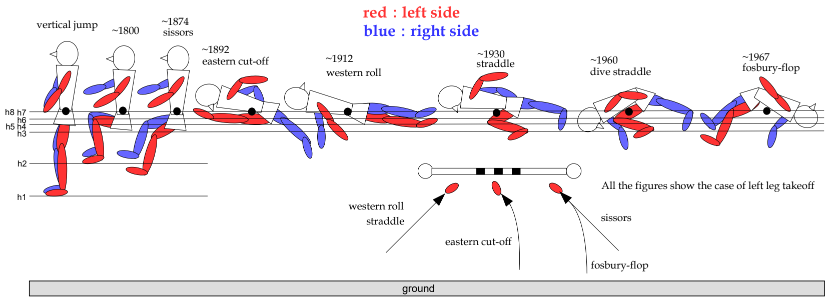

Figure 1.2: Historical change of clearance

The western roll was also used at the same age as the eastern cut-off and was used at least in 1912. The Athlete lifts the leg farthest from the bar first, and the his side is to the bar as the body passes over. Sometimes we call "rollover" those with the back facing down when crossing the bar. Western roll technique technique is shown at the Fig.1.2 and can jump h5 height (same as h4).

The western roll was flowed by the "straddle". The straddle was used at least in 1919. The athlete cleared the bar face-down and moved parts of the legs to be lower than bar at the peak of the jump. This method lifts the pelvis higher than western roll. The straddle technique is shown at the Fig.1.2 and can jump h6 height (higher than h4 and h5).

The straddle was evolved into dive straddle (Sometimes we call "Soviet style straddle") by the Soviet Union athletes in the 1960's. The athlete cleared the bar same as the straddle but drop the head and trunk to be lower than bar at the peak of the jump. This raised lower body and can jump higher than simple straddle. The dive straddle technique is shown at the Fig.1.2 and can jump h7 height (higher than h6).

The last born technique is "fosbury flop". This innovative jumping style was born in the late 1960's. In 1968 Dick Fosbury won the Olympic Games and spread fosbury flop to the world. Since then many athletes came to use this style. The athlete cleared the bar with his back facing down, and the body and the ground is parallel. When viewed from above, it was a jumping form with an air posture where the bar and the body could be viewed at right angle. As of 2017 the men's world record is 2.45m and women's world record is 2.09m. Both world records were achived by fosbury flop. The fosbury flop technique is shown at the Fig.1.2 and can jump h8 height (same as h7). The fosbury flop and the dive straddle are said to be jumping methods to jump the same height, but the fosbury flop is easier to learn jumping technique and is now the mainstream jumping method.

Year	Record[m]	Year	Record[m]	Year	Record[m]
1912	2.00	1960	2.195	1984	2.39
1914	2.01	1960	2.22	1985	2.40
1917	2.02	1961	2.23	1985	2.41
1924	2.03	1961	2.24	1987	2.42
1933	2.04	1961	2.25	1988	2.43
1934	2.06	1962	2.26	1989	2.44
1936	2.07	1962	2.27	1993	2.45
1936	2.07	1963	2.28		
1937	2.08	1970	2.29		
1937	2.09	1971	2.29		
1941	2.09	1973	2.30		
1941	2.10	1976	2.31		
1941	2.105	1976	2.32		
1941	2.11	1977	2.33		
1953	2.12	1978	2.34		
1956	2.15	1980	2.35		
1957	2.16	1980	2.35		
1960	2.17	1980	2.36		
1960	2.17	1983	2.37		
1960	2.18	1983	2.38		

Figure 1.3: Men's high jump world record (table)

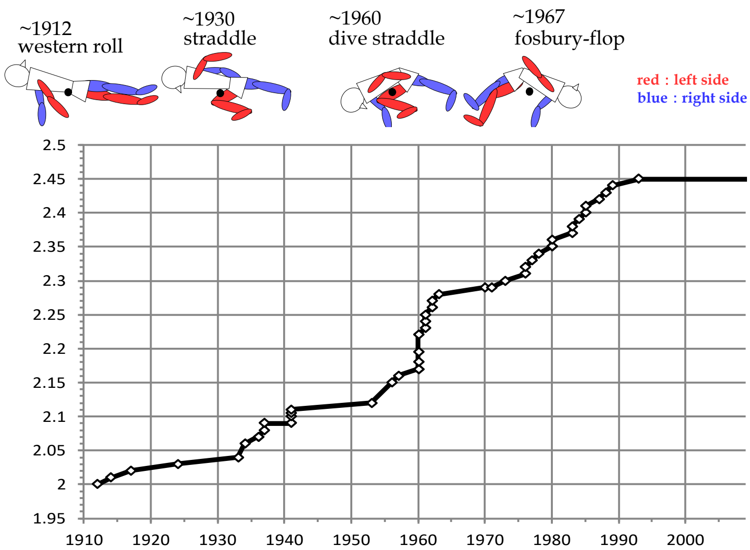

Figure 1.4: Men's high jump world record (graph)

Year	Record[m]	Year	Record[m]	Year	Record[m]
1922	1.46	1956	1.76	1976	1.96
1923	1.485	1957	1.76	1977	1.96
1923	1.485	1957	1.77	1977	1.97
1925	1.524	1958	1.78	1977	1.97
1926	1.552	1958	1.80	1977	2.00
1926	1.58	1958	1.81	1978	2.01
1928	1.58	1958	1.82	1978	2.01
1928	1.595	1958	1.83	1982	2.02
1929	1.605	1959	1.84	1983	2.03
1932	1.62	1960	1.85	1983	2.03
1932	1.65	1960	1.86	1983	2.04
1932	1.65	1961	1.87	1984	2.05
1939	1.66	1961	1.88	1984	2.07
1941	1.66	1961	1.90	1986	2.07
1941	1.66	1961	1.91	1986	2.08
1943	1.71	1971	1.92	1987	2.09
1951	1.72	1972	1.92		
1954	1.73	1972	1.94		
1956	1.74	1974	1.94		
1956	1.75	1974	1.95		

Figure 1.5: Women's high jump world record (table)

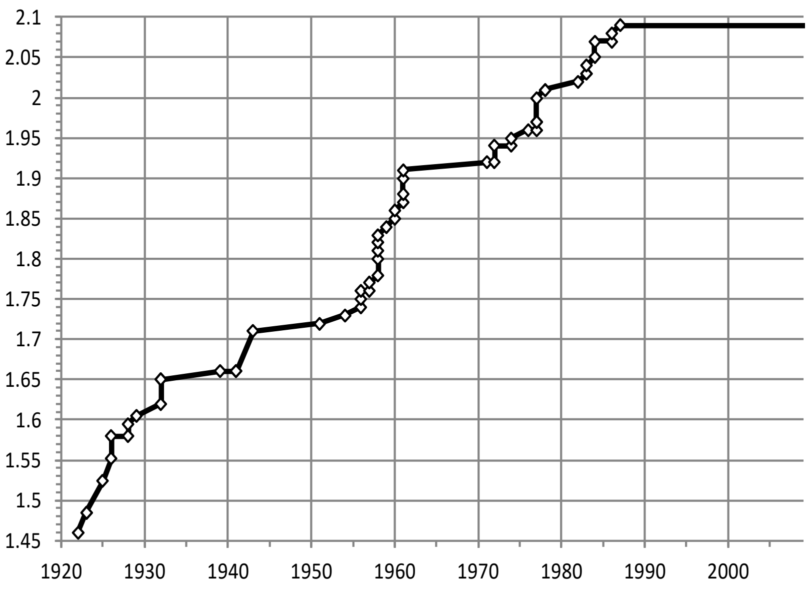

Figure 1.6: Women's high jump world record (graph)

Chapter

2

Basic knowledge of Physics

2.1 Law of physics

Physics can handle only simple model or simplified model in many case. However, the result of the equation is always accurate.

There are many training method in the world. Many instractor who say their orignal training method. But the method against the law of physics is incorrect. And you can think of the correct training method by understanding law of physics.

There are three important forces in high jump

1. Gravity
   Gravity is a force pulling together all matter. Gravity of the earth is the main force working on the athlete.

2. Reaction force received from contacted object
   For every action force, there is an equal and opposite reaction force. The Athlete is recieved reaction forces from all contacted objects (e.g. ground).

3. Inertial force
   Inertial force is a force that resists a change in velocity of an object. The athlete is received centrifugal force (kind of inertial force) at curve approach.

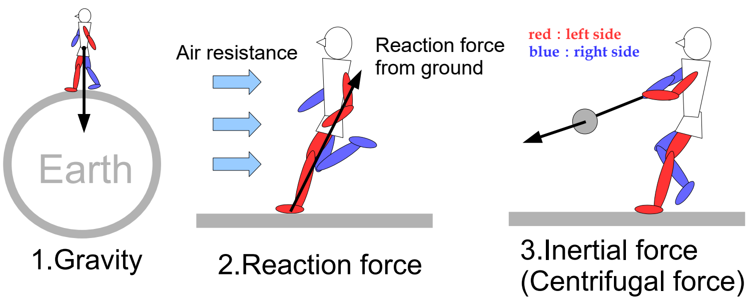

Figure 2.1: Three important forces in high jump

2.2 All forces to an athlete during curve approach

- The forces to an athlete during curve approach are gravity force, reaction force from ground and centrifugal force.
- The centrifugal force increases as the turning radius of the curve approach decreases and as the run-up speed increase
- If the centrifugal force at the curve approach increases, it becomes easier to create an inward inclined posture. Inward inclined posture produces low center of gravity and fast run speed.

The forces to an athlete during curve approach are gravity force, reaction force from ground and centrifugal force (Fig.2.2).

The centrifugal force F of an object rotating at a constant speed is represented by the following equation.

$$F = \frac{Mv^2}{r} \tag{2.1}$$

This formula expresses that the centrifugal force increases as the turning radius of the curve approach decreases and as the run-up speed increases. If the centrifugal force of the curve approach increases, it becomes easier to create an inward inclined posture at curve appoach. Inward inclined posture produces low center of gravity and fast run speed.

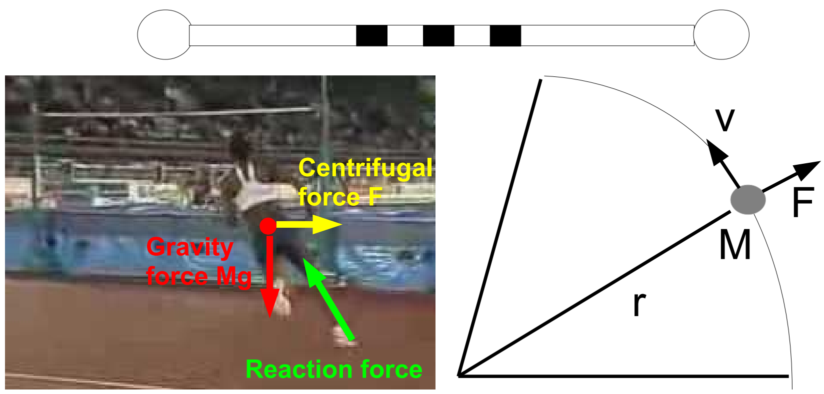

Figure 2.2: Relationship between centrifugal force and curve approach

2.3 Reaction force during take off motion

The athlete receives a reaction force from the ground and jump to the sky.

The reaction force from ground is constructed from three elements

1. Ground reaction force generated by collision between foot and ground
2. Ground reaction force generated by extension motion of take off leg
3. Ground reaction force generated by arm and swing-up leg action.

The first reaction force is the force generated passively. This force is the same as the reaction force generated between the rod and the ground when the rod is thrown to the ground.

The second and third reaction forces are the active forces generated by muscle power of an athlete. When a "heavy object" such as a trunk, arms and legs is lifted upward at take off motion, the other parts of the body are pushed with the same force in the direction of the ground (downward) according to the law of action / reaction. The active force to raise the "heavy object" is finally transmitted as the force to push the ground and the body receives the rising reaction force from the ground.

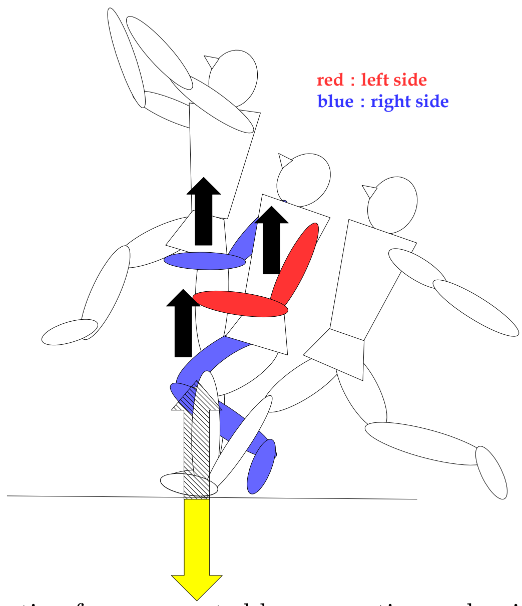

Figure 2.3: Reaction force generated by arm action and swing-up leg action

Fig.2.3 shows the reaction force generated by arm action and swing-up leg action. By lifting the arms and legs (the red and blue parts in the figure), other body parts (white parts in the figure) are pushed in the direction of the ground according to the law of action / reaction. By this force pushing the ground (yellow part in the figure), repulsive force from the ground (oblique arrow in the figure) is obtained and lifting force of the body is created. Because the weight of the legs is more than three times the weight of the arms, it can produce a stronger lifting force than the arms.

2.4 The center of gravity

- The center of gravity is the central point of body weight
- The center of gravity is the average position of all the mass points
- The center of gravity is the point at which that region blances perfectly

The center of gravity of the homogeneous material rod is in the center of the rod. The center of gravity of standing man is roughly 56% of body height. The center of gravity may not be inside the body in the clearance phase.

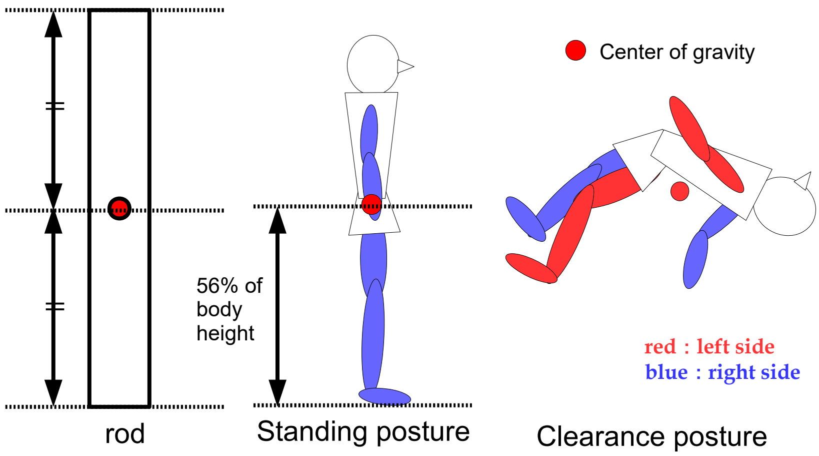

Figure 2.4: The center of gravity of an object

Here we define each mass of mass point as $m_1, m_2, \ldots, m_N$, the total mass of mass points as $M = \sum_{i=1}^{N} m_i$. N is the number of body segments. We define each position vector of mass point as $\mathbf{r}_1, \mathbf{r}_2, \ldots, \mathbf{r}_N$.

The position of the center of gravity $\mathbf{R}$ is given by following equation.

$$\mathbf{R} = \frac{\sum_{i=1}^{N} m_i \mathbf{r}_i}{\sum_{i=1}^{N} m_i} = \frac{\sum_{i=1}^{N} m_i \mathbf{r}_i}{M} \tag{2.2}$$

When analyzing the movement of the center of gravity of an athlete, we often divide the body into several segments (body parts) and calculate the position of the center of gravity from there.

If we measure motion of the body using motion capture, the position of the center of gravity can be obtained. The weight and the position of the center of gravity for each segment of the body part have been measured by many studies.

2.5 Center of gravity motion during clearance

- The center of gravity orbit is parabola during clearance
- The center of gravity orbit is determined at the moment away from the ground
- The center of gravity orbit can't changed by clearance motion
- The maximum height of the center of gravity is fixed at the moment away from the ground

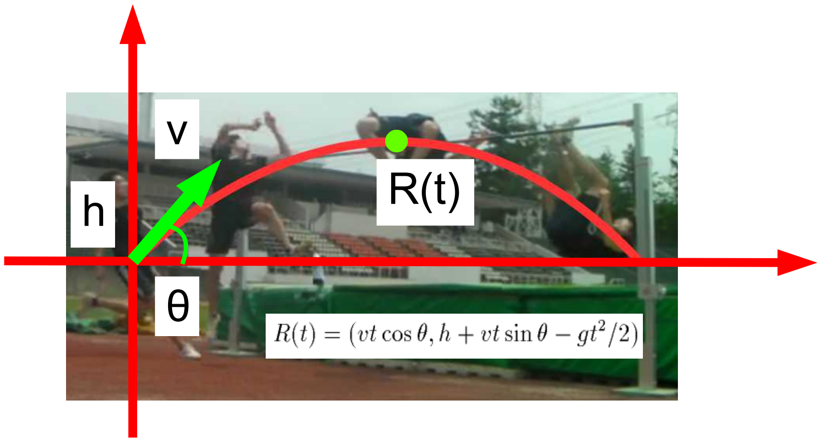

Figure 2.5: The center of gravity orbit during clearance

Here we define the total mass of body segments as $M = \sum_i^N m_i$, the position of the center of gravity as $\mathbf{R}$. Define all external forces on body segments as $\mathbf{F}^{(ex)} = \sum_i^N \mathbf{F}_i^{(ex)}$. N is the number of body segments.

At this time, the following relational expression is obtained.

$$M\frac{d^2\mathbf{R}}{dt^2} = \mathbf{F}^{(ex)} \tag{2.3}$$

This equation represents "The center of gravity orbit during clearance depends on external forces, don't depends on internal forces." So the center of gravity orbit during clearance is not variant even if muscle forces (internal forces) change the clearance posture. External forces during clearance are gravity and resistance of air.

Let $\mathbf{R}(t)$ be the position of the center of gravity at time t, g be the gravitational acceleration value, v be the velocity, θ be the jumping-out angle, h be the height of the position of the center of gravity. v, θ, and h are the values at the moment when the center of gravity jumps out into the air.

If we ignore air resistance, the movement of $\mathbf{R}(t)$ is calculated as following equation.

$$\mathbf{R}(t) = (vt\cos\theta, h + vt\sin\theta - gt^2/2) \tag{2.4}$$

This equation represents the parabolic trajectory of the center of gravity during clearance operation.

2.6 Rotational motion

- Rotational motion is created by the moment of force
- Even if the mass is the same, an object with many masses located near the center of gravity is easy to rotate

Rotational motion is created by the moment of force. The moment of force is defined as following equation.

$$\mathbf{M} = \mathbf{r} \times \mathbf{F} \tag{2.5}$$

In this equation, $\mathbf{M}$ is the moment of force. $\mathbf{r}$ is the position vector of mass point. $\mathbf{F}$ is the vector of force. $\mathbf{M}$ becomes larger as $\mathbf{F}$ is larger and as the moment arm is longer.

The relationship between $\mathbf{M}$ and angular acceleration $\boldsymbol{\beta}$ is calculated as following equation.

$$\mathbf{M} = \mathbf{I} \cdot \boldsymbol{\beta} \tag{2.6}$$

Where, $\mathbf{I}$ denotes the moment of inertia. $\mathbf{I}$ is a physical quantity representing the ease of rotation of the object. Even if the mass is the same, an object with many masses located near the center of gravity is easy to rotate. At this time, the value of $\mathbf{I}$ takes a small value.

The angular momentum $\mathbf{L}$ is a physical quantity representing the momentum of rotation. The angular momentum $\mathbf{L}$ is defined as following equation ($\mathbf{p}$ represents the momentum of the object).

$$\mathbf{L} = \mathbf{r} \times \mathbf{p} \tag{2.7}$$

$\mathbf{L}$ is the exterior product of $\mathbf{r}$ and $\mathbf{p}$.

The relationship between the angular momentum $\mathbf{L}$ and the moment of force $\mathbf{M}$ is calculated as following equation.

$$\frac{d\mathbf{L}}{dt} = \mathbf{M} \tag{2.8}$$

This equation shows that the time change of angular momentum is determined by $\mathbf{M}$.

The relationship between the angular momentum $\mathbf{L}$ and the angular velocity $\boldsymbol{\omega}$ is calculated as following equation.

$$\mathbf{L} = \mathbf{I} \cdot \boldsymbol{\omega} \tag{2.9}$$

2.7 Rotational motion during clearance

- The angular momentum required for clearance is only generated by take off motion
- If the posture is changed and the moment of inertia is changed, the athlete can rotate their body faster or slower during clearance

Here we define the mass of mass point i as m_i, the position of mass point i as $\mathbf{r}_i$, internal force between the mass point i and j as $\mathbf{F}_{ij}^{(in)}$, external force for the mass point i as $\mathbf{F}_i^{(ex)}$. N is the number of body segments. At this time, the total angular momentum of the mass system $\mathbf{L}$ is given by the following equation.

$$\frac{d\mathbf{L}}{dt} = \sum_{i}^{N}(\mathbf{r}_i \times \mathbf{F}_i^{(ex)}) \tag{2.10}$$

This equation shows that internal forces $\mathbf{F}_{ij}^{(in)}$ (such as muscle force of human body) and the change of total angular momentum of the mass system $\frac{d\mathbf{L}}{dt}$ (such as human body) are irrelevant.

The external forces acting when a human is in the air are only gravity forces except for air resistance. The total moment of the extarnal forces (gravity forces) $\mathbf{N}_G^{(ex)}$ based on the center of gravity is given by the following equation.

$$\mathbf{N}_G^{(ex)} = \sum_{i=1}^{N}\{(\mathbf{r}_i - \mathbf{R}) \times m_i\mathbf{g}\} = 0 \tag{2.11}$$

In this equation $\mathbf{R} = \frac{\sum_{i=1}^{N} m_i\mathbf{r}_i}{M}$ represents the position of the center of gravity (M is the total mass of body). This formula expresses that if the human body moves away from the ground, the angular momentum around the center of gravity will not change with gravity.

The angular momentum around the center of gravity does not change either by internal force (muscle force) or by external force (gravity) during clearance. The angular momentum required for clearance is only generated by take off motion.

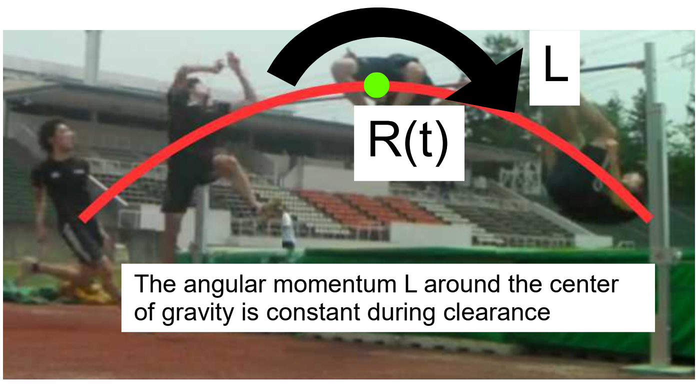

Figure 2.6: The angular momentum during clearance

2.8 Relationship between moment of inertia and angular velocity during clearance

If we collect the mass of body at the center of rotation (bending their back) during clearance, the angular velocity of the body becomes faster.

Even if the angular momentum **L** is constant during clearance, if the posture is changed and the moment of inertia **I** is changed, the athlete can rotate their body slower or faster.

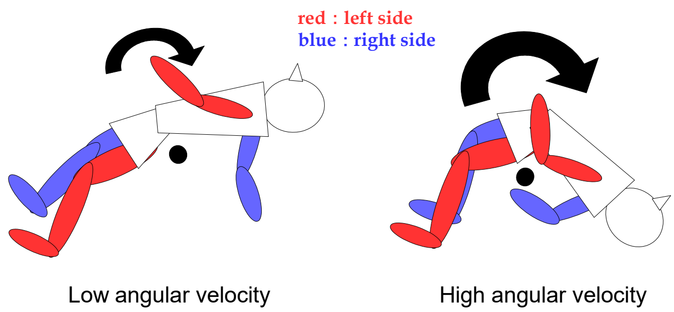

Figure 2.7: Difference in clearance posture and angular velocity

If the athlete bends knees and bends their back as shown on the right in Fig.2.7, the athlete can take a position of the body where the moment of inertia becomes smaller than the athlete on the left in Fig.2.7. As a result, even if the athlete with the same angular momentum and same parabolic trajectory of the center of gravity, the athlete on the right can rotate the body faster in the air.

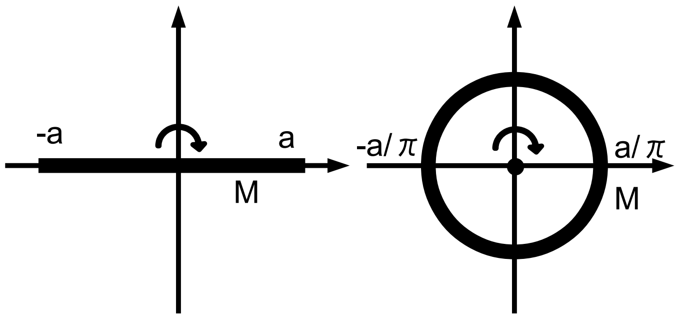

Figure 2.8: Calculation example of moment of inertia

As shown in the Fig.2.8 left side, we assume that the body of the athlete is an elongated rod of length 2a and a mass M. At this time, the value of the moment of inertia about the axis of rotation when the body is in the form of a straight rod is $I = \frac{1}{3}Ma^2$ (Fig.2.8 left side). The value of the moment of inertia around the axis of rotation when the rod is rounded to a circle is $I = \frac{Ma^2}{\pi^2}$ (Fig.2.8 right side).

By roughly calculating, the moment of inertia is reduced to 1/3 by rounding the straight rod to a circle. And the rotation speed (angular velocity) is about tripled during clearance since the relational expression between I, L, and ω is $L = I\omega$.

2.9 Joint moment and power

The joint moment

- The joint moment is the moment which is generated by muscle force around joint.
- Normally, the joint extending direction is taken as the positive value of the joint moment,
  the joint bending direction is taken as the negative value of the joint moment.
- Many instruments and software for joint moment analysis are now on the market, and the muscular load of various sports motions had been analyzed in detail.
- If the leg is on the ground, the ground reaction force affects greatly to joint moment. If the leg is separated from the ground, the influence of the inertial force becomes large.

The joint power

- The power is a physical quantity expressed by multiplying speed and force.
- When the muscle is afferently contracting, the power takes a positive value.
- When the muscle is eccentrically contracting, the power takes a negative value.

The joint moment is generated by muscle force around joint. Normally, the joint extending direction is taken as the positive value of the joint moment, the joint bending direction is taken as the negative value of the joint moment.

The power P is calculated as following equation.

$$P = M\omega \tag{2.12}$$

Where, M denotes the moment of joint and ω denotes the angular velocity of joint. The power is a physical quantity expressed by multiplying speed and force. The power is intuitively easy for the athlete to understand.

When the muscle is afferently contracting, the power takes a positive value. When the muscle is eccentrically contracting, the power takes a negative value. Muscles can exert stronger force in eccentrically contracting than in afferently contracting.

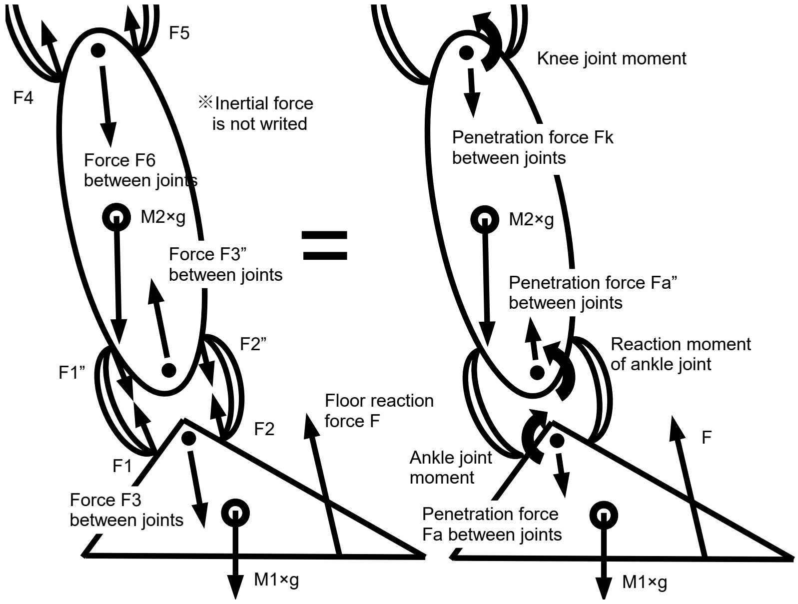

Figure 2.9: The Forces and moments around joint

Here, we show how to calculate joint moment. First calculate the moment of the ankle joint. The force applied to the foot is the floor reaction force F, the gravitational force of the foot part M_1g, the force received from the lower leg part (inter-joint force) F_3, the muscle tension force of the plantar flexion muscle F_1, and the muscle tension force of the dorsal flexion muscle F_2. Also, the inertial force M_1a born by the acceleration of the foot part is added.

$I_1\beta_1$ is the summention of the moment due to F, the moment due to M_1g, the moment due to M_1a, the moment due to F_1, and the moment of force due to F_2. Where I_1 is the moment of inertia of foot. And β_1 is angular acceleration of foot. Since the joint force F_3 passes through the center of the ankle joint, it is not necessary to consider the influence of the moment of force.

The value of I_1 and M_1 have been investigated in many papers. The value of β_1, a are obtained by motion measurement such as motion capture. The value of F is obtained by a floor reaction force plate. Finally we can calculate the ankle joint moment generated by F_1 and F_2 if we know these things.

If the ankle joint moment is calculated, the knee joint moment can also be calculated. The force applied to the lower leg part is the gravitational force of the foot part M_2g, the force received from the foot (reaction force form inter-joint force F_3) $F_3^{"}$, the muscle tension force of the plantar flexion muscle $F_1^{"}$, the muscle tension force of the dorsal flexion muscle $F_2^{"}$, the force received from the upper leg part (inter-joint force) F_6, the muscle tension force of the extension muscle F_5, and the muscle tension force of the dorsal bent muscle F_4. Also, the inertial force born by the acceleration of the lower leg part is added.

The moment of force due to the force $F_1^{"}$, $F_2^{"}$, and $F_3^{"}$ applied to the lower leg part from the foot can be summarized as the moment of force due to the reaction of the ankle joint moment and the moment of force due to the force $F_a^{"}$ (the combined force of $F_1^{"}$, $F_2^{"}$ and $F_3^{"}$). The penetration force between joints $F_a^{"}$ can be calculated from the equation of motion of the foot using measurement data.

As in the case of the ankle joint, the sum of the moments of the forces acting on the lower leg part equals $I_2\beta_2$, so the sum of the knee joint moments by F_4 and F_5 can be calculated.

Many instruments and software for joint moment analysis are now on the market, and the muscular load of various sports motion had been analyzed in detail.

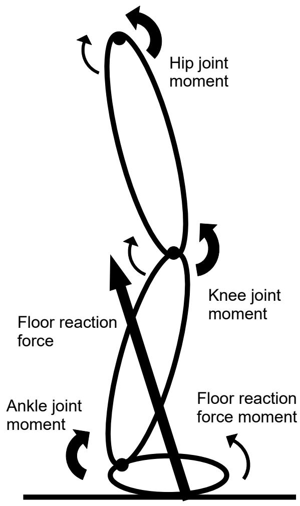

Figure 2.10: The moments around joint during ground contact

It is known that the moment due to the floor reaction force has a large influence on the joint moment in the walking motion or the running motion where the foot contacts the ground.

For example, when the floor reaction force vector passes the front of the ankle joint during walking, a dorsiflexion direction moment of the ankle joint is generated by the floor reaction force. At this time, the athlete generates plantarflexion direction moment of the ankle joint.

Likewise ankle joint, when the floor reaction force vector passes the behind of the knee joint during motion, a flexion direction moment of the knee joint is generated by the floor reaction force. At this time, the athlete generates extension direction moment of the knee joint. The same goes for the hip joint.

It is extremely important for the athlete to think about the direction of the floor reaction force around the joint. The more the direction of the floor reaction force moves away from the joint axis, the load on the joint becomes stronger. The more floor reaction force becomes stronger, the load on the joint becomes stronger. Heavy load of joint causes an overload and failure.

On the other hand, when the leg steps away from the ground in the running motion, no floor reaction force exists and the influence of the inertial force increases. Since the inertial force increases in proportion to the acceleration of each part of the body, a large inertial force acts on the joint during the leg swing phase with fast running. If the leg is on the ground, the floor reaction force is greatly affected to joint moment, and if it is separated form the ground, the influence of the inertial force becomes large.

Chapter

3

Runup

3.1 Key points of runup

The key points of runup (curve approach) are as follows

- Run fast
- Keep the center of gravity low
- Keep the center of gravity as constant height as possible

The optimal runup approach depends on the jumping style of the athlete, but some common features are seen in good athletes.

The first important thing is to run fast. In the take off motion, the velocity energy in the horizontal direction is converted to the position energy in the vertical direction. Therefore, if you think simply, the athlete can jump higher as their runup speed increase.

Generally speaking, it is said that about 80% of the maximum speed is a good runup speed. The average of first-class athlete runup speed at the start of take off motion is 7.8[m/s]. This is a very fast speed.

The second important thing is to keep the center of gravity low. In order to jump higher, it is necessary to convey a large force to the ground for a long time. In other words, it is good to jump such that the force product (force × time) becomes large. Therefore, if the athlete lowers the center of gravity and obtains the maximum movement width in the vertical direction as much as possible during the take off phase, the athlete can jump higher.

The third important thing is to keep the center of gravity at constant height. In curve approach, control the center of gravity's trajectory as constant as possible. And it is good that the center of gravity rises up while drawing a smooth curved trajectory during the take off motion. Many top athletes runup like that. It is easier to control the height of the center of gravity if stride is short and hangtime of step is short.

3.2 Framework of runup

The framework of runup is as follows

- Left-footed athlete runs from the right side facing the bar
  Right-footed athlete runs from the left side facing the bar
- Perform J type runup which combines linear approach and curve approach
- Auxiliary approach may be added to the linear approach.

The general runup of the high jump consists of three parts.

1. Auxiliary approach
   Auxiliary approach runs before linear approach (walk several steps, skip lightly, etc) This is done to make it easy to take the start timing of the runup.

2. Linear approach
   The part that runs straight. It is done to obtain sufficient running speed before curve approach.

3. Curve approach
   The part that runs curve. It is done to control the position and speed of the center of gravity during takeoff motion.

Beginners practice J type runup thoroughly until runup motion becomes stable. It is important to find the stride and rhythm that suits athlete's feeling. Try starting with a setting of about 6 straight approach and about 5 steps of curve approach. The distance should be based on Fig.3.1.

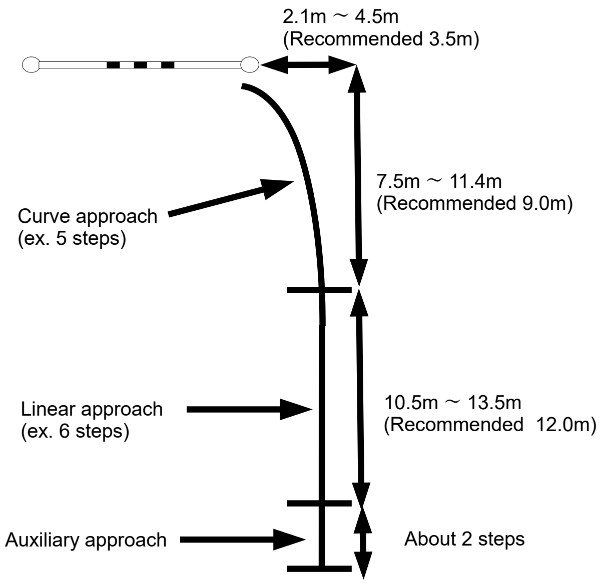

Figure 3.1: The exsample of runup approach

3.3 Inward tilting motion

With inward tilting running motion, athlete can runup with keeping the center of gravity low without losing the running speed

Inward tilting motion is a technique to incline the body inward that uses the centrifugal force of curved approach.

The more athlete's running form resemble natural running forms, athlete can run fast. Inward tilting motion helps natural running forms during the curve approach. With inward tilting running motion, athlete can runup with keeping the center of gravity low without losing the running speed.

If athlete run fast or run with a small curve, the centrifugal force will be stronger during the curve approach. If there is a large centrifugal force, it becomes easy to make naturally inward tilting motion during curve approach. When running fast, be careful not to lean body too much forward while running.

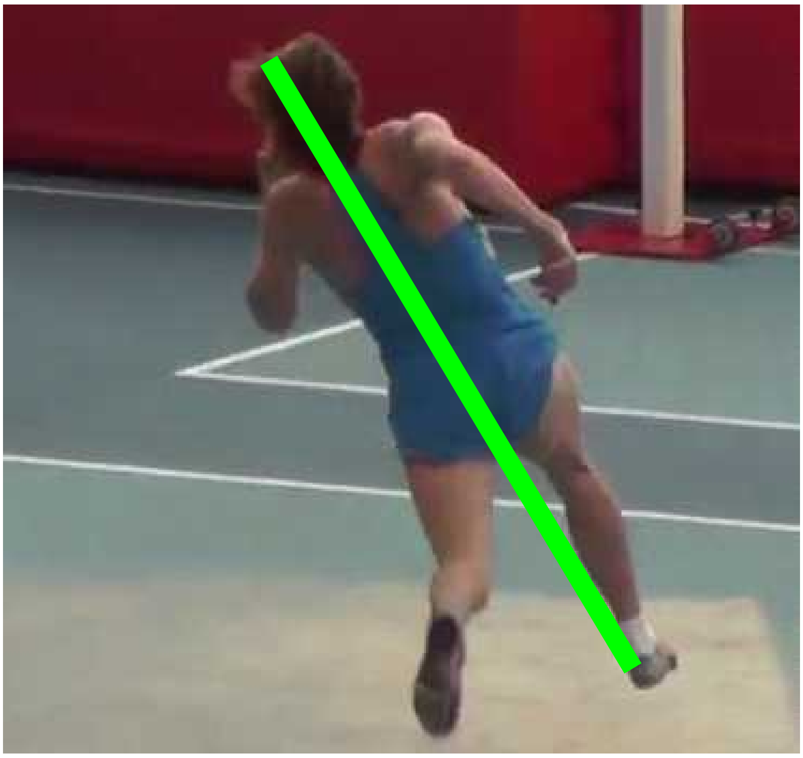

Figure 3.2: Inward tilting running motion

3.4 Backward tilting motion

If the athlete makes a backward tilted posture at touch down moment of takeoff motion, the athlete can increase the vertical movement distance of the center of gravity during takeoff motion (it is easy to obtain a large impulse)

Backward tilting motion is a technique to incline the body backward at touch down moment of takeoff motion.

In order to obtain a large vertical velocity during takeoff motion, the impulse has to be increased. If the athlete makes a backward tilted posture, the athlete can increase the vertical movement distance of the center of gravity during takeoff motion (it is easy to obtain a large impulse). It is said that it is better to make backward tilting posture without bending the knee.

Figure 3.3: Backward tilting posture during takeoff motion

3.5 Inward tilting and backward tilting at take-off motion

Average posture of inward tilting

- At the moment of touching down the ground, the trunk tilts about 15 degree inward
- At the moment of takeoff from the ground, the trunk does not tilt more than 10 degree in the direction approaching the bar

Average posture of backward tilting

- At the moment of touching down the ground, the trunk tilts about 15 degree backward
- At the moment of takeoff from the ground, the trunk does not tilt forward

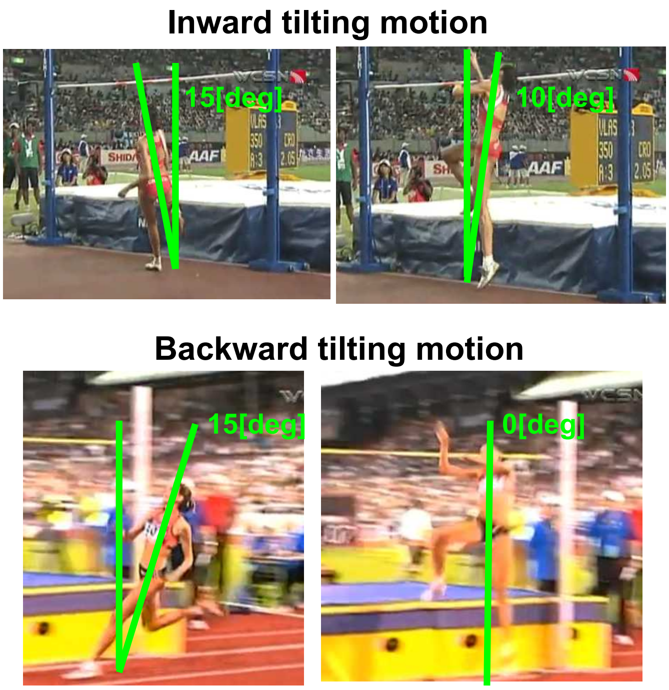

Figure 3.4: Inward and backward tilting motion

The values shown in the Fig.3.4 are average values. Depending on the jumping style, the optimum values may be smaller or larger than these values.

In general, the angle of inward tilting becomes maximum at two steps before takeoff motion. At one step before takeoff motion, the inward tilting motion and the backward tilting motion overlap each other and the height of the center of gravity becomes the lowest. From there the center of gravity rises smoothly with a large curvature orbit towards takeoff.

3.6 Arm action and jumping style

- There are three kinds of arm action, running arm, single arm, and double arm
- Jumping style is roughly divided into speed type and power type

How to use the arm before takeoff motion is classified into ”running arm”, ”single arm”, and ”double arm”.

Speed type jumpers often use running arm action. Power type jumpers often use double arm action. In addition, middle type jumpers often use single arms. Speed type and power type jumpers have the following characteristics.

Characteristics of speed type jumper

- Approach distance is long
- Running speed is fast
- Raising motion (arms and legs) is small and quick
- Contact time to the ground is short
- Backward tilting motion is small
- Takeoff position is far from the bar
- Jumping angle is small (jumping distance is long)
- Arch in the air is small

Characteristics of power type jumper

- Approach distance is short
- Running speed is slow
- Raising motion (arms and legs) is big
- Contact time to the ground is long
- Backward tilting motion is big
- Takeoff position is close to the bar
- Jumping angle is large (jumping distance is short)
- Arch in the air is big

A typical arm action method will be described here. I will explain with the left-footed athlete as an example. Here, the right hand and leg are drawn in blue, the left hand and leg are drawn in red.

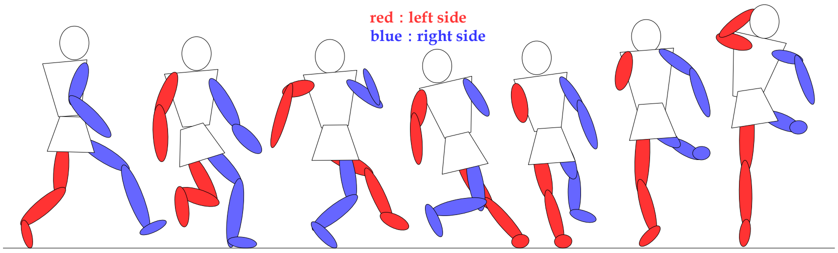

Figure 3.5: Running arm action

Fig.3.5 shows the typical running arm action.

In the running arm action, swing the left arm forward and swing the right arm backward at takeoff phase. By doing this, the arms and legs become natural movements similar to running motions. Movement of the foot and arm reverses in the same way as the running motion.

In the takeoff motion, raise the body with a swing-up leg (right leg) and a left arm. At this time, make a takeoff posture like pulling the left shoulder upward.

Disadvantage

- The center of gravity at takeoff phase is low
  (It is difficult to take a posture pulling up arms and legs)
- It is difficult to make large force to the ground by using arms and legs in the takeoff motion
- Because the backward tilting motion becomes smaller, it is difficult to obtain the rotational force in the air
- Because the rotational force is small, arch in the air becomes small

Advantage

- Because it can move with near-running motion, it is possible to perform a fast takeoff motion without decelerating
- Because the approach speed is fast, it is easy to takeoff far from the bar.

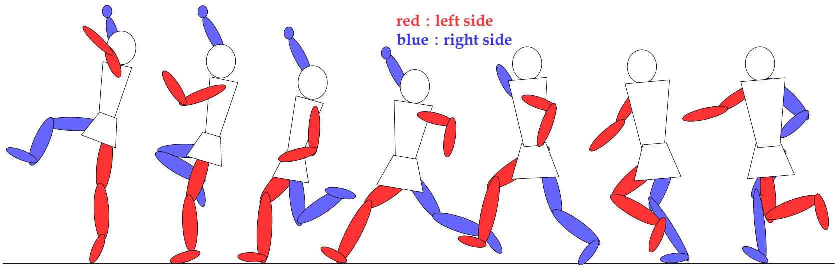

Figure 3.6: Single arm action

Fig.3.6 shows the typical single arm action.

In the single arm action, swing the left arm forward and keep the right arm forward at takeoff phase. Many athletes do the takeoff motion in posture in which the right shoulder is pulled upward rather than the left shoulder.

The advantage of single arm action is easy to control body from takeoff motion to clearance. Also, although the running speed decreases compared to the running arm action, there is also an advantage that it is easy to take the backward tilting posture in the takeoff motion. Single arm action tends to be used favorably for athlete with fast running speed.

Next, the double arm action will be explained. With the double arm action, set the left leg forward and the right leg and both arms behind at the start of the takeoff motion. There are two kinds of operation of the double arm action.

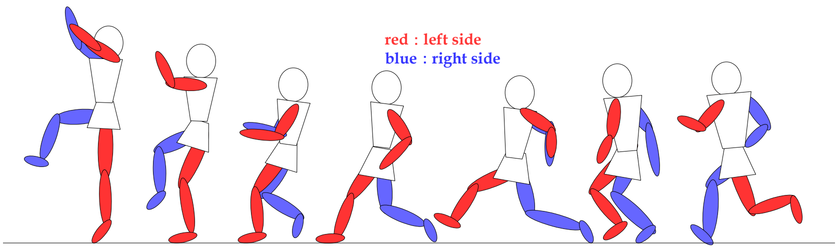

Figure 3.7: Double arm action -a-

Fig.3.7 shows one of the double arm action. When the right foot before takeoff motion contacts the ground, the left arm goes forward and the right arm goes backward. And when the last step is taken, the left arm goes naturally backward and the right arm keeps behind. In the takeoff motion, both arms are swinging out strong from the back to the front.

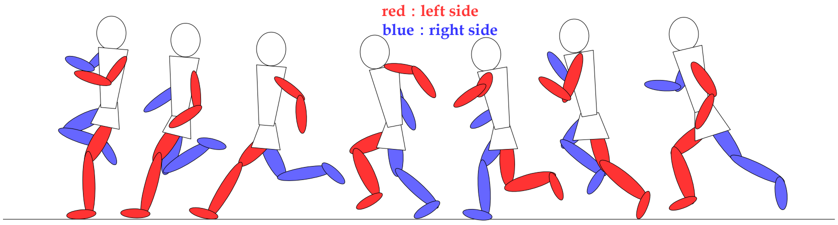

Figure 3.8: Double arm action -b-

Fig.3.8 shows a double arm different from Fig.3.7. When the right foot before takeoff motion contacts the ground, the both arms go forward. And when the last step is taken, the both arms go naturally backward. In the takeoff motion, both arms are swinging out strong from the back to the front.

Compared to the previous double arm action, there is a big difference in that the right arm is left forward in the first half of the arm action.

Disadvantage

- Because the way of using the arm becomes unnatural compared to normal running motion, the running speed tends to slow down.
- Because the approach speed is slow, it is difficult to takeoff far from the bar

Advantage

- The center of gravity at takeoff phase is high
  (It is easy to take a posture pulling up arms and leg)
- It is easy to make large force to the ground by using arms and legs in the takeoff motion
- Because the backward tilting motion becomes larger, it is easy to obtain the rotational force in the air
- Because the rotational force is large, arch in the air becomes large

Chapter

4

Takeoff motion

4.1 Rotational motion by the stiffened body axis during takeoff motion

Rotational motion by the stiffened body axis during takeoff motion makes in a large upward force and rotational force.

If a straight rod is thrown to the ground obliquely as shown in the Fig.4.1, the speed in the horizontal direction is converted to upward force and the rotational force. At this time, the faster you throw, the rod jumps higher. Physical phenomena similar to rods occur even at takeoff motion of high jumper.

Figure 4.1: Rotational motion by the stiffened body axis during takeoff motion

Important points are summarized as follows.

- Keep the center of gravity low, and run fast
- Make backward tilting posture, and increase the distance of takeoff
- Resist not to bend knee by the reaction force from the ground
- Make takeoff times as short as possible
- Make the body like a straight rod at the moment of touch down and lift the body straight up

4.2 How to use muscles during the takeoff motion

A large body lifting force is generated when the muscular strength resists the force to bend the lower body's joints in the first half of the takeoff motion.

In the first half of the takeoff motion, the extension muscle groups of the leg generate a large muscle force by extensional contraction. The explosive force generated by this extensional contraction creates the lifting force (Vertical velocity Vz) of the athlete.

Fig.4.2 shows the change between knee joint angle and Vz of CG during takeoff motion. In this figure, Vz rises greatly in the first half of the takeoff motion while the knee joint bends. Vz does not change so much in the latter half of the takeoff motion while the knee joint extends.

It is known that an initial vertical velocity about 80% is produced by extensional contraction by the time the knee is bent to maximum. This means that highjump jumping method is fundamentally different from vertical jump.

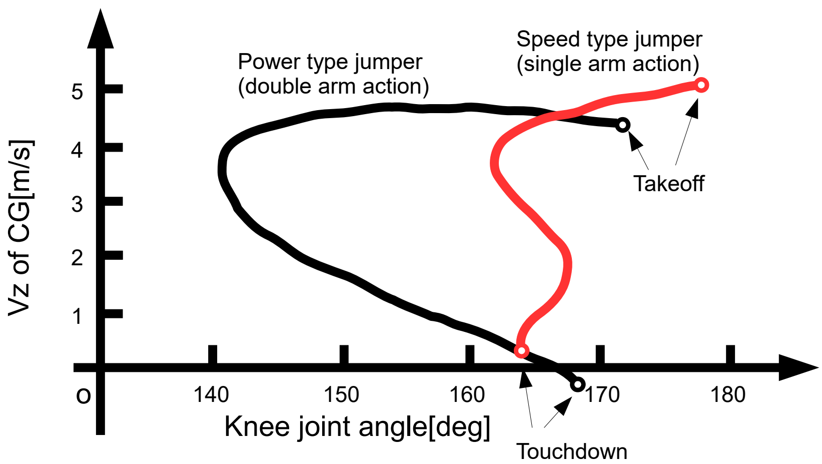

Figure 4.2: Relationship between knee joint angle and Vz of CG

Also, the ground contact time of high jump is about 0.1 second to 0.25 second, which is extremely short compared with other jumping sports. Some research shows that the higher the athlete can jump, the shorter the ground contact time is.

In the takeoff motion, it is important to "shorten the ground contact time" and "resist not to bend the knee by the reaction force from the ground".

4.3 Quantitative target value of takeoff motion

- The last step is done in a short time of about 0.2 seconds
- Set the angle between the takeoff foot and the bar to about 30 degrees
- Distance of takeoff position is more than about 1 meter from the bar

Many top athletes runup motion have been researched in the past research.

Top athletes are able to perform compact and short time step before takeoff motion. The last step length of top athletes is about 2.1 meter and is done in a short time of about 0.2 seconds. Many top athletes are doing compact takeoff motion.

Top athletes set the angle between the foot and the bar to about 30 degrees. A beginner tends to set the angle between the takeoff foot and the bar to parallel. But this makes a heavy load to the ankle, and is also difficult to takeoff with a fast approach speed.

The distance of takeoff position is more than about 1 meter from the bar in the case of top athletes. The distance of takeoff position tend to be increased as athlete jump higher.

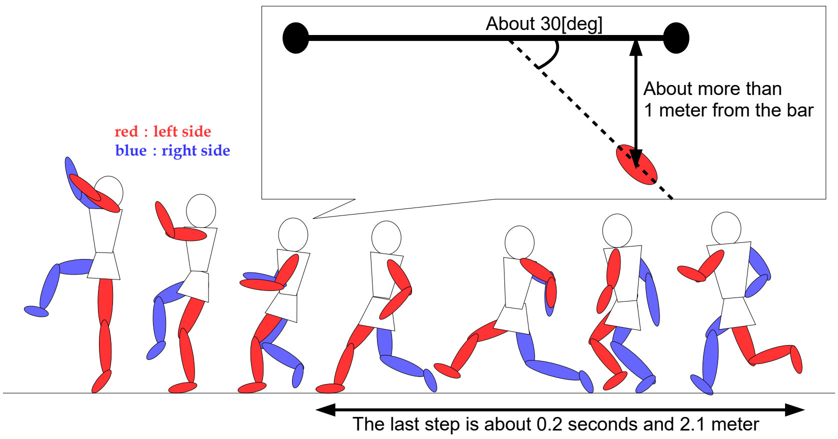

Figure 4.3: Quantitative target value of takeoff motion

Chapter

5

Clearance

5.1 Adjustment of rotational component during clearance

The rotation components necessary for clearance is generated by takeoff motion.

The rotational components (angular momentum) generated by takeoff motion are the following three.

- Roll rotation
  The rotation around the axis on the horizontal plane parallel to the traveling direction of the takeoff motion. The rotation component is mainly generated by inward tilting motion.
- Pitch rotation
  The rotation around the axis on the horizontal plane perpendicular to the traveling direction of the takeoff motion. The rotation component is mainly generated by backward tilting motion.
- Yaw rotation
  The rotation around the axis perpendicular to the ground. The rotation component is generated from the movements of swing-up leg, shoulders, and arms.

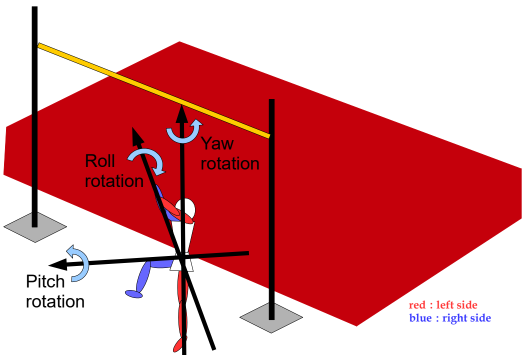

Figure 5.1: Rotation component of clearance

In the case when the athlete does not make arch properly, or when the hip is easy to hit the bar, the rotation component in the direction of the bar (Composite component of pitch rotation and roll rotation) is often insufficient. In this case, check whether the inward tilting motion or the backward tilting motion is insufficient.

For the athlete whose pitch rotation component is stronger than other athletes (for the athlete with large back tilting motion), more yaw rotation is needed for clearance. If the yaw rotation is insufficient, swing-up leg side hip tends to become lower during clearance motion. In this case, check whether the movement of the swing-up leg is small.

The athlete whose pitch rotation component is weaker than the other athletes (the athlete with small back tilting motion) is less likely to bend their back properly during clearance motion. In this case, many athletes make their distance of takeoff position far from the bar and lengthening the time that can be rotated in the air.

The female athletes jumping time (time in the air) is shorter than the male athletes. For this reason, the female athletes need greater roll, pitch, and yaw rotation components than the male athletes for clearance. The female athletes may require special inward tilting motion, backward tilting motion, arm action, swing-up leg motion, and clearance motion compared to the male athletes.

5.2 Posture adjustment

Adjustment of posture during clearance

- If the athlete lowers the position of head or knee by bending their back, they can lift their hip
- If the athlete collects the mass of body at the center of rotation (bending their back), the body's speed of rotation increases
- The athlete can adjust their posture during clearance using the action and reaction force.

The center of gravity orbit does not change in the air, but athlete can lift another parts by lowering some parts of the body. For example, if the athlete lowers their head, bend their knees and lower their legs, the athlete can lift their hip.

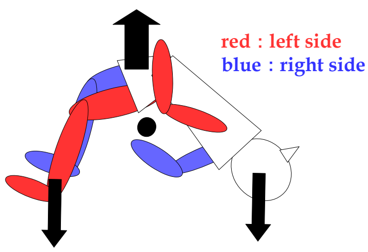

Figure 5.2: Arch adjustment motion during clearance

The total angular momentum does not change in the air, but it is possible to rotate faster or slower by adjusting the moment of inertia (ease of rotation) by changing the posture of the body.

It is important to adjust the posture of body in the air so that the athlete does not touch the bar. For example, the athlete whose angular momentum is small or the athlete whose jumping time is short had better take a posture with a small moment of inertia (a posture bending their back).

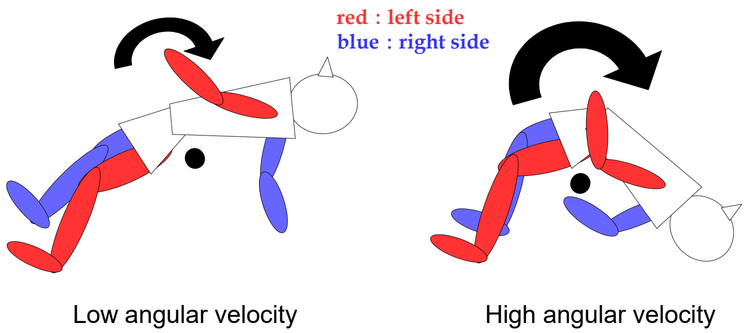

Figure 5.3: Angular velocity adjustment motion during clearance

Although the angular momentum and the center of gravity trajectory in the air do not change, the athlete can adjust their posture during clearance using the action and reaction force. For example, as shown in the Fig.5.4, if the athlete rotates the right arm and the right leg clockwise, the rest of the body rotate counterclockwise.

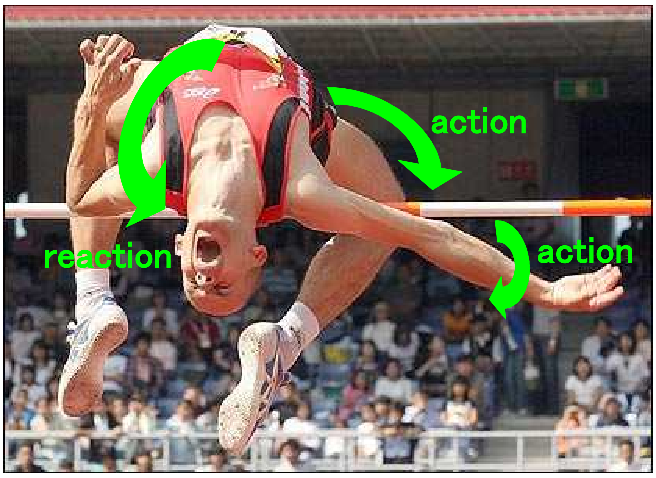

Figure 5.4: Posture adjustment motion during clearance

Top athletes use various techniques to adjust their posture so as not to touch the bar in the air.