

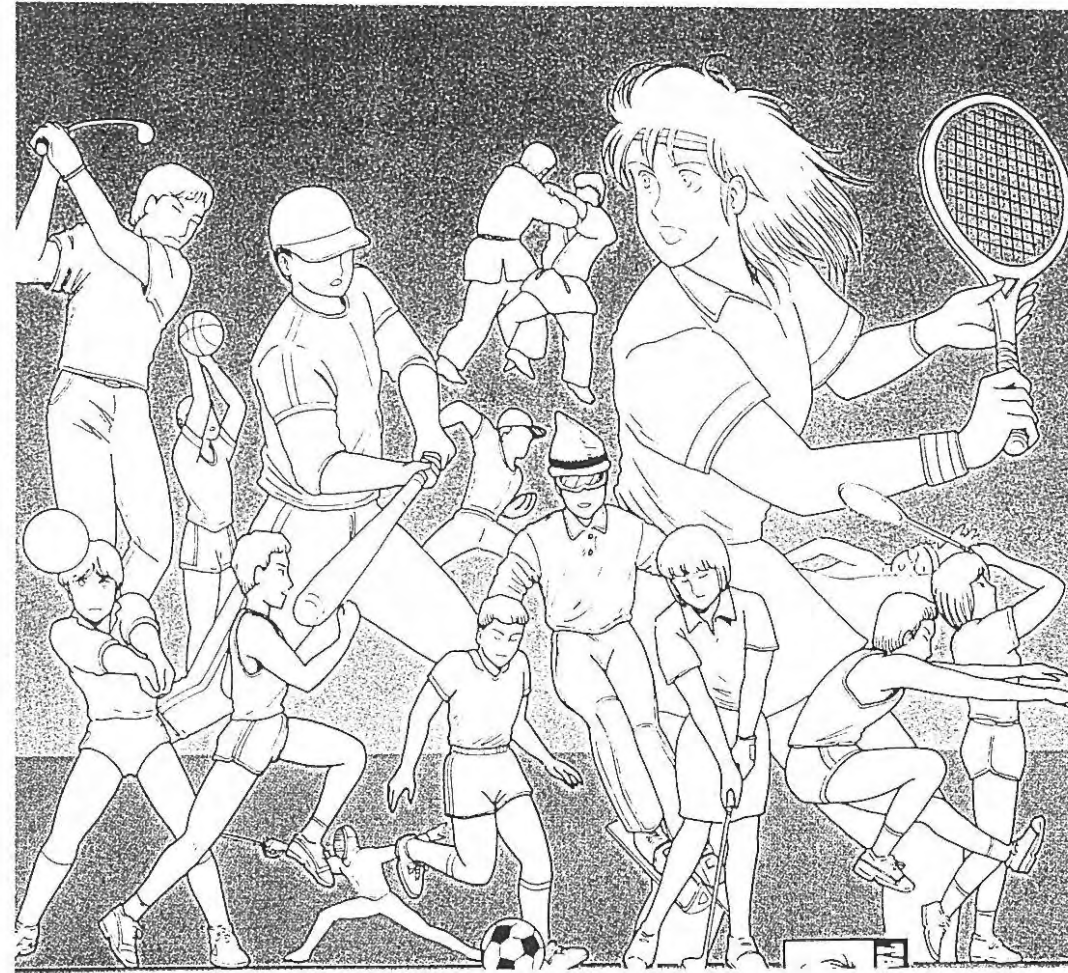
Jan. '96

DYNAMICS FOR IMPROVING SPORTS PERFORMANCE

Illustrated Principles of Sports Movements

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Illustration by Hitoshi Utsunomiya



Introduction

"Isn't there any proven road to success in sports?" This must be a question asked by anyone who has tried various sports, achieved little improvement, and bit the proverbial dust. Even without such an experience, you may have wondered, "Is it right to keep practicing by trying to imitate the form of top players, with no clearly defined strategy? Isn't there a more scientific training method?"

This book was written for all of you who have asked such questions. It explains the bodily movements involved in various sports, or sports movements, using basic physical laws easy enough for everybody to understand. Until now, general beliefs held that physical bodily movement was so complex that it was incomprehensible and beyond scientific analyses. In this book, we attempt to refute this assertion, drawing on basic everyday experiences.

Human movement basically follows the simple laws of motion, which are involved in sports movements in various ways. By making use of these principles in a systematic manner, you will surely improve your skills.

Instructions in many sports guidance books have presented such advice as, "if you follow these tips, you can improve your skills," with "tips" such as: Put more snap in your wrist, " or "Use you entire body like a whip." Yet, these assertions almost always rely on groundless "hunches," which are so unscientific that I have never felt convinced of their efficacy.

I personally enjoy sports very much and have read extensively about them, including some highly technical books. But most literature merely explains easy concepts, avoiding crucial points. The reader is left wondering whether the authors really understand what they are talking about.

This is unfortunate in an era in which sports have become valuable human activities to be shared by all people. People can enjoy not only sports, but also highly advanced social life in general, by understanding scientific perspectives that enrich life and culture, in addition to making use of scientific technologies. In fact, such an approach is indispensable for anyone living in the modern age. Science should not be monopolized by a limited number of specialists; rather, it should belong to everyone.

As a high school physics teacher, I have tried to find answers to these questions and somehow convey the enjoyable aspects of science to as many people as possible. Going back to the basics of physics, I reasoned that a human body has certain mass, which can be moved by certain amount of 'force'.

This force cannot exist all by itself. In other words, force cannot appear without following the principle of action and reaction. Based on this knowledge, I have tried to explain the mechanisms of various sports movements. Is it that simple? In fact, this approach enables analysis of various movements that until now have been considered unexplainable.

Of course, actual sports movement cannot be fully explained by pure kinetics and dynamics that regard them only as simple, discreet movements of an object. Physiological (muscle strength and flexibility) and psychological (mental toughness and concentration) aspects are equally important. Furthermore, only when these factors optimally interact with each other, allowing the athlete's mind and body to work in tandem can exceptional performance be achieved. If aspects of movement involving kinetics, which have until now remained ambiguous, are clarified, we will have made great strides toward performance improvement.

Of course, some sports require certain innate physical compositions or abilities, but everyone can find at least one or two sports quite suitable for his or her physique and preferences. There are ways for everyone to alleviate stresses placed on muscles or joints and to improve their sports techniques safely, using a scientific perspective that uses

the body rationally and efficiently.

Without doubt, there is no ceiling, or final developmental stage, in any sport: As athletes increase their skills, they come to know themselves better, to devise and pursue their own unique practicing methods. It is my hope that, through reading this book, you will be able to grasp the essence of sports movements, model your own unique training methods, and upgrade your sports abilities.

This book seeks to fundamentally reexamine various sports movements using its unique perspective, and to clarify them using scientific concepts and laws of motion. Of course, this approach has not yet been perfected, so please let me know of any ambiguities that you may perceive.

I owe a great deal to Mr. Shuji Tsuji of Taiga Publishing Co., Ltd. for publication of this book. Although I have long been keenly interested in the subject of this book, honestly speaking, I had hesitated to write a book about it. It was Mr. Tsuji, who shares similar ideas, who first requested me to write this book. Without his strong enthusiasm and support, this book might not have been completed. Part of the material presented in this book previously appeared in a periodical series entitled "Mathematics Seminar" (Nippon Hyoron-sha Publishing Co., Ltd.) and was favorably reviewed. Special thanks are extended to Mr. Taiki Sato who edited this book, and last but definitely not least, to my friends at "Galileo Workshop" (represented by Yoji Takikawa), a study and practice circle for physical education.

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60. Bodily movements can be explained by these models!
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62. You can hammer a nail harder if you stop your hand!
63. Snapping is "action-reaction"!
64. A strong step in kendo (Japanese fencing) is a kind of snap?
65. A yo-yo goes up with a snap!
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67. "Fighting with both arms" is forearm turning!
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73. Forearm turning also helps uncock!
74. Forearm turning ensures a great shot! *Rebound*

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75. Sink first to jump high!
76. Take an arm back quickly and hit hard!
77. Tactics that use reactive motions! *rebound*
78. Consecutive techniques made possible by reactive motions! *rebound*
79. "Fresh" reactive motions create power! *rebound*
80. Hit a nice volley in the same way as snapping a coin!

Epilogue: The key phrase is still "action and reaction".

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Prologue

What do these sports movements have in common?

A backhand volley in tennis, a heading in soccer, and a place kick in rugby: what do these sports movements have in common? All of them involve hitting a ball to the best possible destination.

Now, if you look closely at these movements, you will realize that something curious is happening immediately before and after hitting the ball. Amazingly, the body part moves in the opposite direction of the ball.

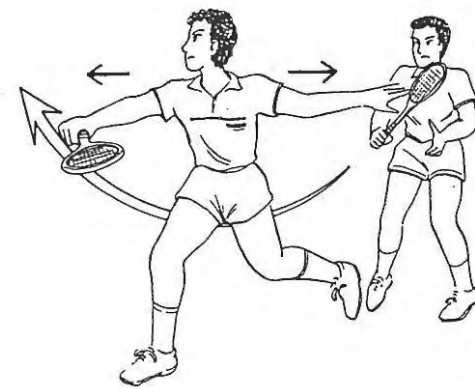
★ Backhand volley in tennis: While the arm holding the racket moves in the direction of the ball, the other arm moves back quickly, even with the fingers tense and straight. (See the figure on the above.)

★ Heading in soccer: At the same time as the head thrusts toward the incoming ball, the arms stretched forward are pulled back quickly. Without this pulling motion, it is impossible to gain enough power to effectively hit the ball. (See the figure middle.)

★ Place kick in rugby: While the kicking right (left) leg moves forward and contacts the ball, the extended left (right) arm is pulled back quickly to the right (left) side of the body. (See the figure below.)

Take baseball as another example. When you swing a bat, your head and body move slightly backward. Since the head and body are heavy, even small movements can have substantial effects.

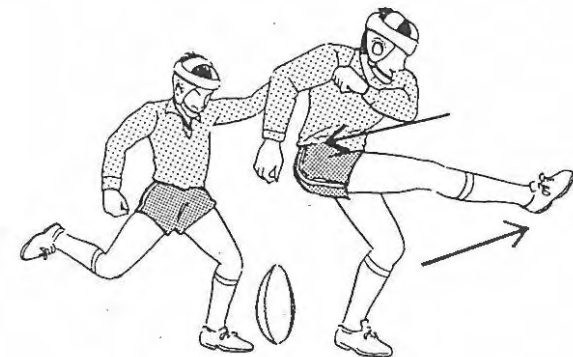
What is common in all these examples is that in order to hit a ball hard and far, certain parts of the body always move in the opposite direction of the ball. In other words, without such movements in the opposite direction, the entire body may lose balance and power. These kinds of movements are the most essential of all sports movements. In this book, we will carefully observe various sports movements, examine the dynamics involved, and consider what is required to improve performance.



★ Backhand volley in tennis



★ Heading in soccer



★ Place kick in rugby

Chapter 1

Sports Movements Action and Reaction

Quiz: Suppose you are lost
in outer space.
How can you get back
to your ship?

Q: A space-shuttle is flying in zero-gravity outer space without air or sound. An astronaut equipped with many repair tools is working outside of the space craft. Suddenly there is an emergency! Inadvertently, he has moved a little too far away from the shuttle.

"Oops! I've got to get back quick."

To make matters worse, he has left behind his gas-propelled gadget for a space walking and his lifeline. If he doesn't act fast, he will drift in space forever.... What should this astronaut do to get back to the shuttle?

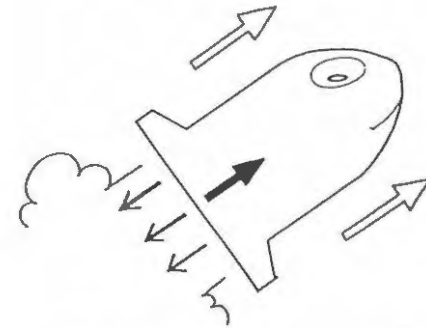
A: He should throw his repair tools in the direction away from the space shuttle. Luckily, he has many tools with him. If he throws them away from the shuttle, he can move toward the shuttle by the reactive force generated.

As evident from this example, all movement requires a reactive force. When a rocket is launched, it utilizes reactive force by blasting out fuel gas or gas particles.

1/ <When lost, you can go back in this way.>

2/ <This is how a rocket flies.>

<When lost, you can go back in this way.>



<This is how a rocket flies.>

1. What is the law that separates the two?

Two skaters are standing on a rink and pushing each other as shown in Figure 1a. This kind of situation, where one pushes and the other pushes back, is called "action and reaction".

In this case, it does not matter which is the "action" and which is the "reaction"; but they always work in pairs. Neither of them can exert force alone, or exert more force than the other. In physics, this relationship is called, the Principle of Action and Reaction.

After action and reaction forces are produced, the two skaters accelerate and part from each other as shown in Figure 1b, and the action and reaction effect no longer works.

But then, if the relationship of action and reaction is always at work, will things always start to move? Not necessarily. Let's think about a situation in which one partner is backed against a wall as in Figure 2. Their hands are pushing each other, creating the relationship of action and reaction.

However, Person B does not actually move. This is because another force is working on her from the wall, which offsets the force from Person A. The forces balance out and she cannot move.

Only Person A actually starts to move because a certain amount of force has worked on an object, Person A.

What must be clearly understood here is the fact that even if the relationship of action and reaction exists, some things start to move but others do not. This can be an important insight for analyzing sports movements.

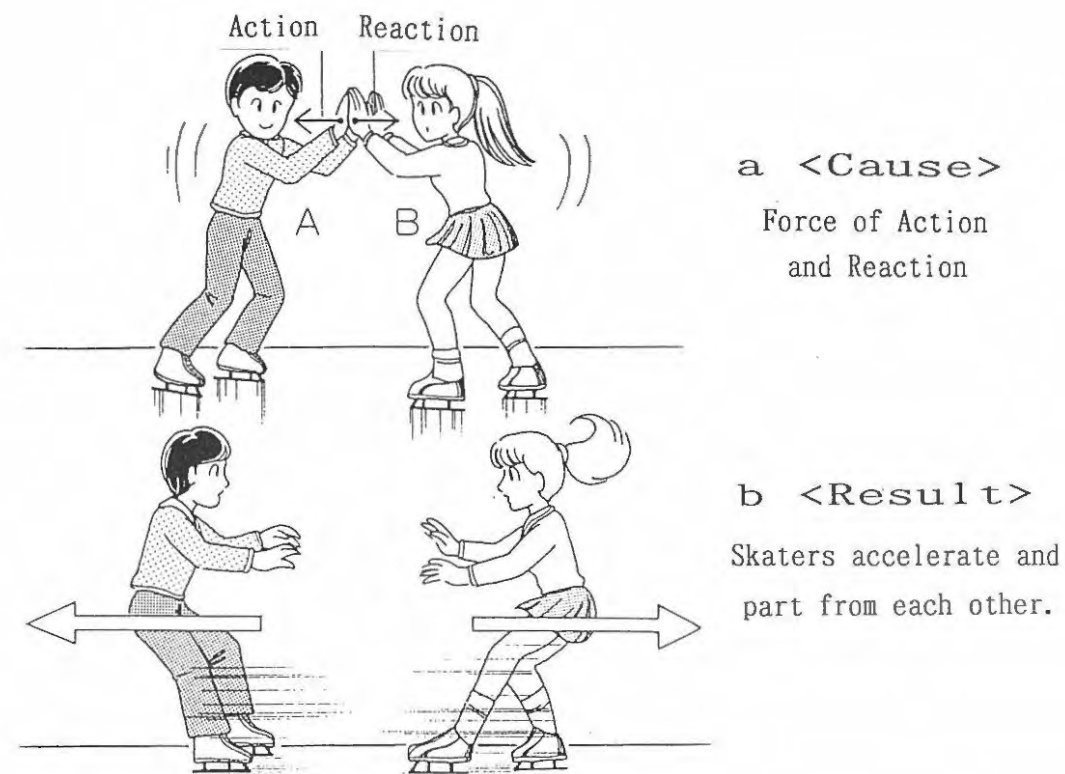


Figure 1: The result of parting from each other has a cause.

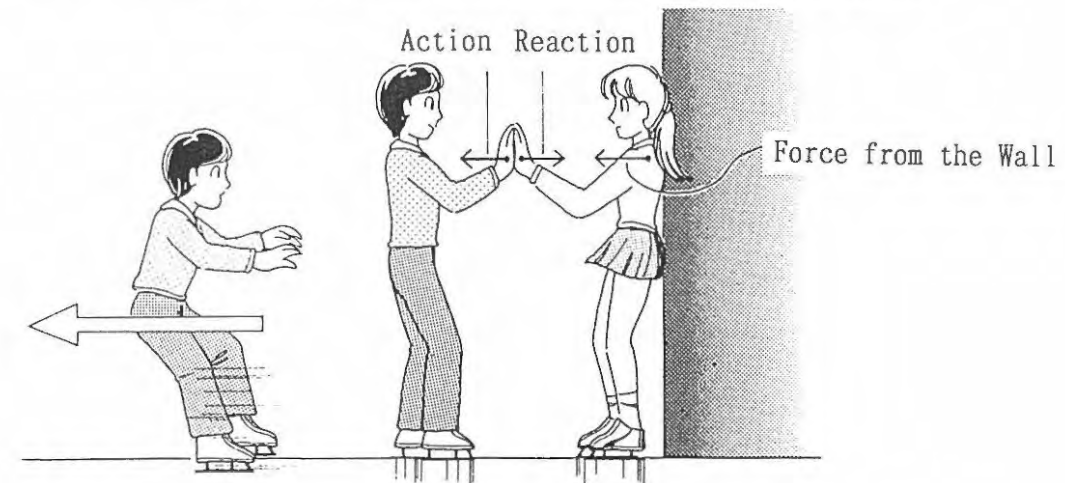


Figure 2: Sometimes the relation of action and reaction does not start a movement....

2. What if a skater throws a ball?

Figure 1 shows a skater throwing a ball with all his might. This skater moves backward due to the reaction force from throwing the ball.

There are several variations of this kind of linear motion caused by "action and reaction". In this section, let's examine some simple patterns in which repulsion and attraction of two objects occur.

Looking at Figure 1, we can come up with an assumption: if we throw a heavier ball or throw a ball at a faster speed, a greater reactive force will be created and further accelerate backward movement.

This can be confirmed by experiments. This "separation" phenomenon, or two objects moving away from each other by repulsion, depends on the mass and velocity of the objects.

Figure 2 illustrates several cases of repulsive motions between two objects with light springs. The effect of "action and reaction" causes the same amount of repulsive force with the springs and provides the same amount of momentum to each object.

After the two objects are separated, the heavier the other object is (thus, the mass is greater), the faster the object moves. Conversely, an object moves more slowly if the other object is lighter in weight (and mass).

In physics, this kind of quantitative relationship is called the Law of Conservation of Momentum, which works whenever two objects separate from each other through the effect of action and reaction. But in this book, instead of this technical term, we attempt to explain all movements only with the concept of "action and reaction".

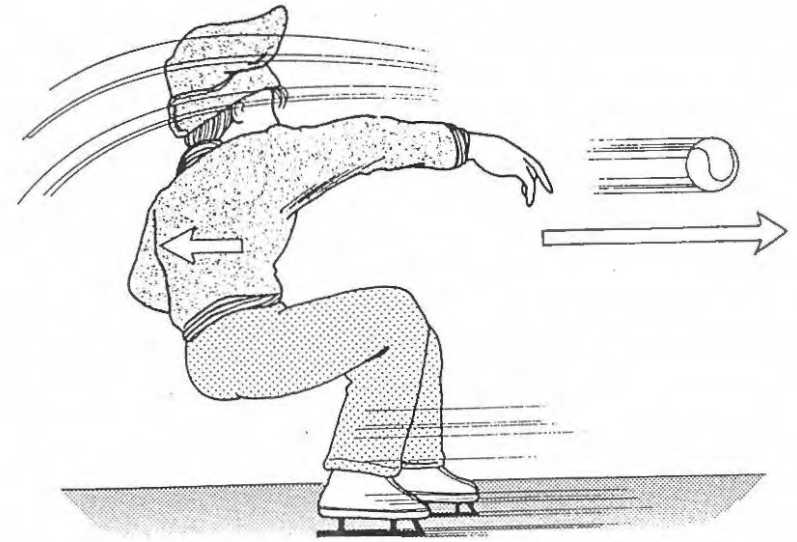


Figure 1: If a skater throws a ball, the reactive force moves him backward.

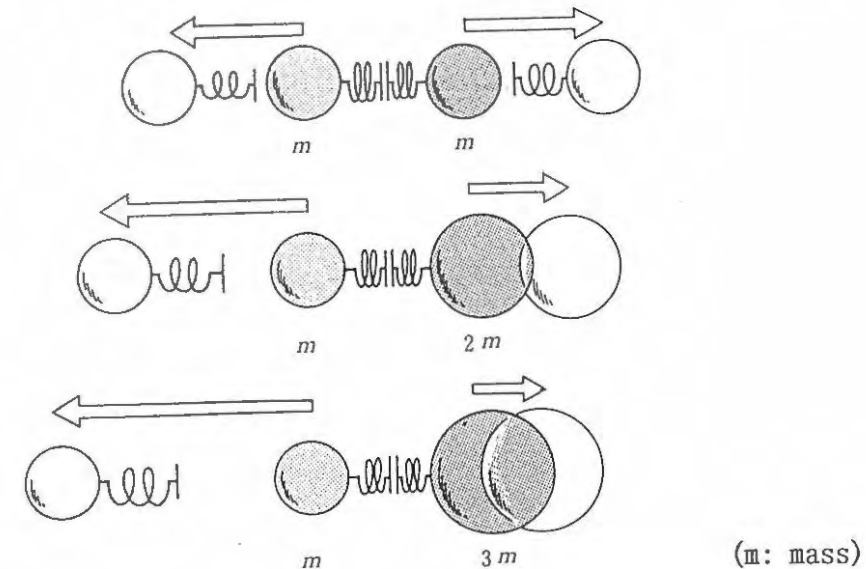


Figure 2: Which gets more power in the repulsion of two objects that have different amounts of mass?

3. Nothing is more effective than a upward arms thrust for a quick squat!

Suppose you are standing upright and are suddenly told to squat. You will most probably thrust your arms upward without knowing it. This is because you can squat quickly by using the thrusting motion as a reaction.

This phenomenon can be explained by separation of force into action and reaction. In other words, it is like a rocket or a jet airplane propelled forward by the reactive force from fuelgas bursting outward.

This squatting motion basically uses muscular power and gravitational pull to lower the body; still, the fact remains that part of the body is used to create reactive force for a faster and stronger movement.

The explanations presented in this book are based on the assumption that all sports movements utilize this principle of action and reaction.

Of course, some may argue that such an assertion cannot be made until the effects of action and reaction are scientifically validated for various sports movements; but you, the reasonable reader, may still perceive from your own experience that you can squat much faster if you simultaneously swing up your arms.

Drawing on such common sense perceptions, this book will explain various sports movements using the basic principles of physics.

<Thrusting up arms enables a quick squat.>



4. A spectacular dunk shot made possible by a downward kicking motion!

Now let's look at how the force involved in various sports movements is separated into action and reaction.

★ Sliding into base (Figure 1)

A runner, lowering his body to avoid being tagged, throws out a leg as far as possible to touch a base. At this moment, as the runner throws up both arms, the "squatting" effect can be observed.

★ Finishing in a race (Figure 2)

In order to reach the finish line faster than others, a sprinter can push his torso forward by utilizing the reaction of thrusting back his arms. This is a hundredth-second moment of truth.

★ Dunking in basketball (Figure 3)

One of the real thrills in a basketball game is the dunk shot- it is like an aerial dogfight. It involves the powerful feat of shooting the ball downwards from above the basket, which is placed as high as three meters above the court. Naturally, it cannot be done without substantial height and tremendous jumping power.

The kick-down motion of the legs is worthy of our special attention. When a player lifts the ball with his arms, the body is pushed downwards.

Conversely, kicking down legs that were previously bent gives additional lift to the body.

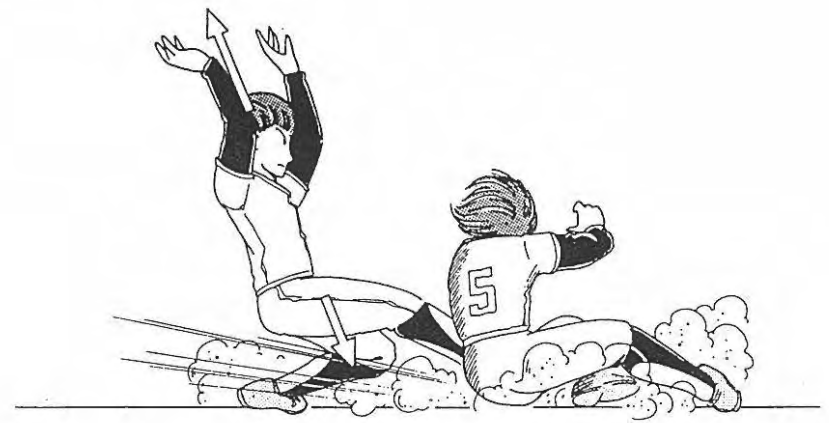


Figure 1: Sliding into base (Safely reaching a base with the arms thrown upward)

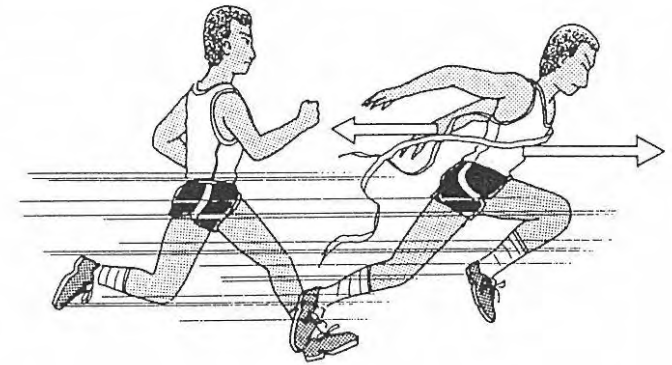


Figure 2: Finishing in a race (Winning by the margin of a torso)

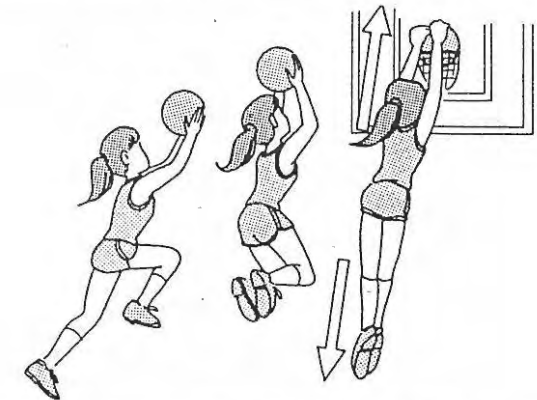


Figure 3: Dunking in basketball (A fabulous dunk shot facilitated by kicking down the legs)

5. Inseparable pushing and pulling!

★ A thrust in karate (Figure 1)

Capitalizing on the reaction force derived from pulling back an extended arm, the attacking arm can be blasted out. The same principle may be applied in boxing. If the pulling power is not strong enough, less strength is available for the attacking arm. Perform this motion and perceive the difference for yourself. As you can see, pushing and pulling are really inseparable.

★ A backhand volley in tennis (Figure 2)

Because a backhand volley is a quick reflex-like motion, there is no time for twisting the body to create the necessary momentum. The reaction force caused by swinging back the free arm is an absolute necessity for making a blasting volley shot.

★ A tennis serve (Figure 3)

When the server tosses up a ball, the effects of "action-reaction" by both arms can be observed, though they are not accompanied by a quick motion. Next, when the ball is hit, the reaction force is effectively utilized by quickly throwing down the free arm.

It should be clear by now that many sports movements require complementing counter-movements in order to maximize athletic potential.

Athletes capitalize on these principles in a wide variety of sports movements. Try to consciously adopt these movements in your sport to improve your performance.

Figure 1: A thrust in karate (Sufficient power cannot be attained without pulling back the other arm.)

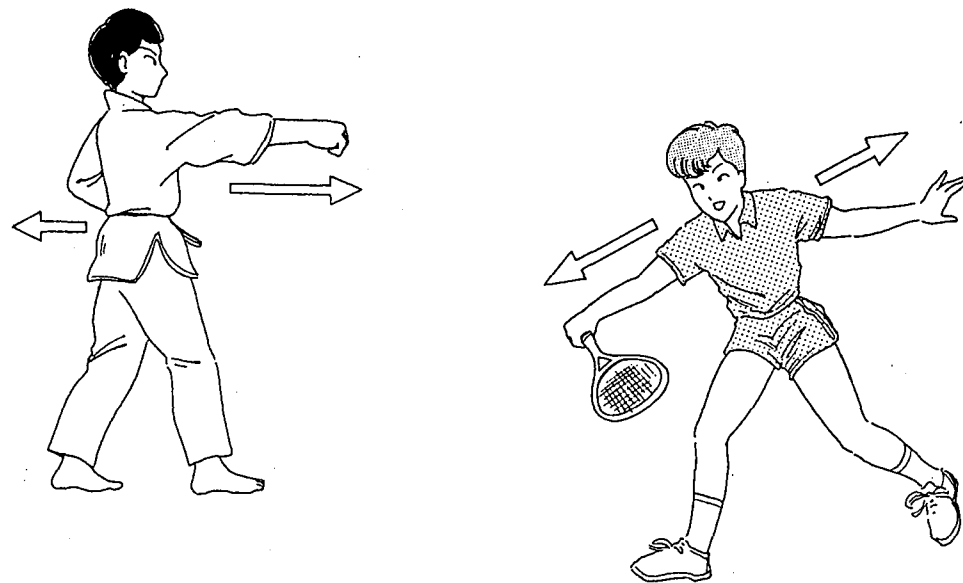


Figure 2: A backhand volley in tennis (Swinging back the other arm enables a terrific volley.)

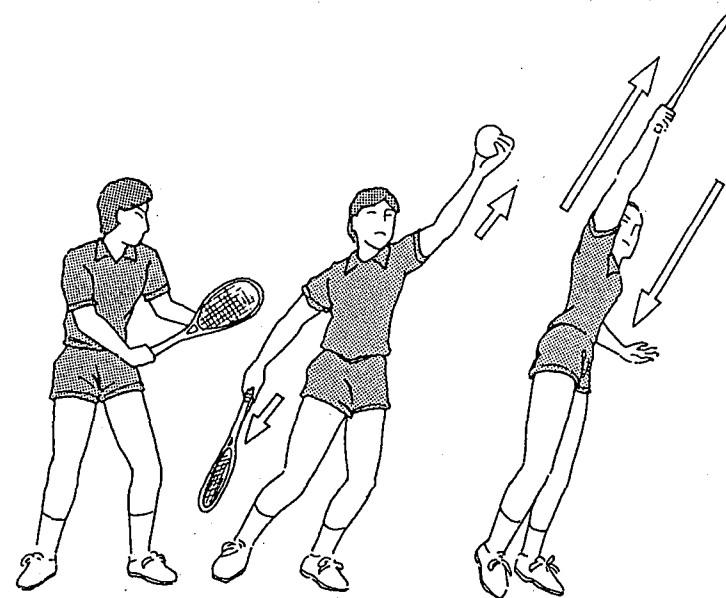


Figure 3: A tennis serve (The ball can be hit more powerfully with complementary movements.)

6. What is the mechanism of moving both arms simultaneously?

Now, let's look into the principle involved when moving both arms simultaneously in opposite directions.

Suppose you are standing on one foot and thrusting out your right arm horizontally as shown in Figure 1. Your torso must be pushed back a little in the direction opposite from the thrusting arm. If you use some weight such as a dumbbell, you will be able to perceive this effect more clearly. This phenomenon can be easily understood as an "action and reaction" effect involving your right arm and body.

What will happen if both arms are quickly extended in the opposite directions as shown in Figure 2? This time, the same force used to thrust the right arm also works between the left arm and the body; that is, the forces on the right and left balance each other, resulting in stabilizing the body. Thus, you can thrust out your arms vigorously and still maintain balance.

Keeping the torso stable means minimizing energy loss, which is very advantageous in various sports. A stable body ensures a steady head and eyes, which enables you to follow the movements of a ball or an opponent accurately.

In this way, using both arms simultaneously will enable you to improve your balance, thrust your arms farther, and perform larger movements. These effects are obvious, for example, in fencing (Figure 3). Yet, because there is no direct interaction between your arms, the "action and reaction" in the strictest sense used in physics is not at work here.

Nonetheless, if you try to thrust an arm quickly and forcefully, you still need to move the other arm in the opposite direction. Thus, we tentatively regard these indirect but intrinsically reciprocal movements of both arms as "action and reaction" in order to facilitate our understanding.



Figure 1: What if you thrust a single arm?
(You will lose your balance!)

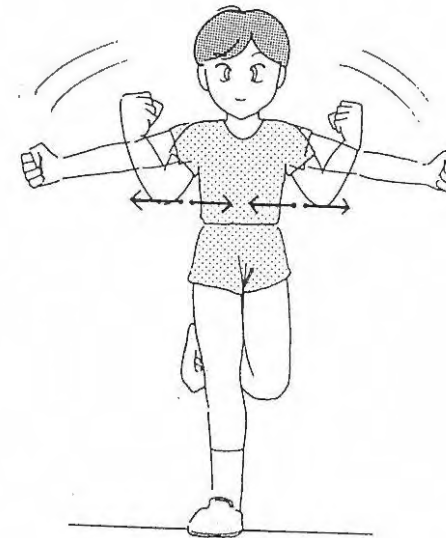


Figure 2: What if you thrust both arms in opposite directions?
(You can secure a stable and forceful motion.)

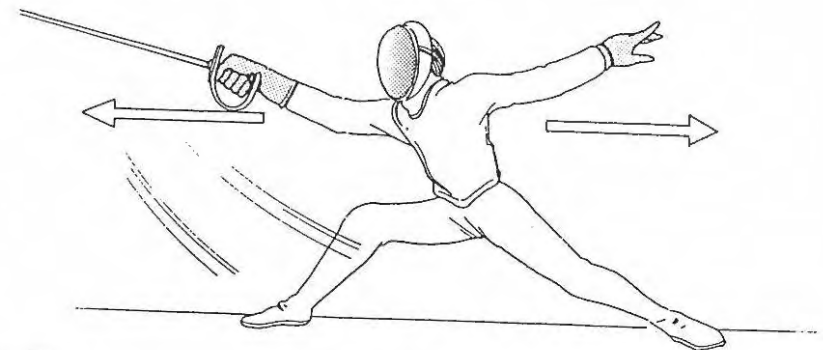


Figure 3: A hit in fencing (The hit can be intensified by movement in the opposite direction.)

Chapter 2

Sports Movements: Rotations Around an Axis

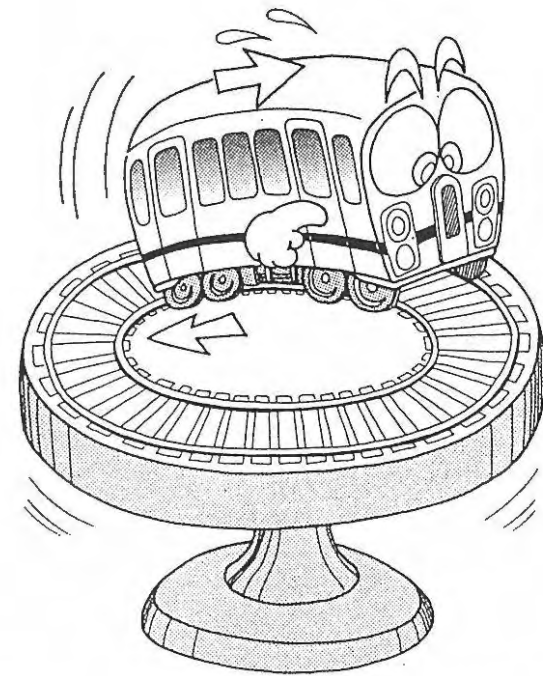
Quiz: What will happen if a train moves around on a round table that can rotate freely?

Q: Imagine rails of a model train along the edge of a light and round table that can rotate almost without friction. Now, suppose the model train moves around on the rails in a clockwise direction; what do you think will happen? In which direction will the table rotate? Or do you think it will remain as it is?

A: The answer is that the table will move counter-clockwise. As discussed in the last chapter, smooth movement of any kind requires some reactive force. In this situation, the train cannot move forward without pushing back the rails. So, the round table moves in the opposite direction, or counter-clockwise.

Some of you may not be convinced yet. Then, try sitting on a swivel chair and swing one arm horizontally to understand the principle involved here. Since friction cannot be reduced to zero in a real swivel chair, it will be more effective if you hold some weight or swing your arm quickly. You will find that your body and the chair rotate in the direction opposite to your arm movement.

In this chapter, we will examine the basic principles of sports movements, such as swinging arms and legs around the body as an axis, and discuss ways to maximize such effects.



(What is the relationship between the rails on the movable round table and a model train?)



(If you sit on a swivel chair and swing an arm,...)

7. The principle of action and reaction in hand-clapping?

As we have seen, if you swing an arm horizontally on a platform that can rotate freely, your body will move with the platform in the direction opposite to arm movement. This is illustrated by the model in Figure 1. In short, the arm and the body are pulling each other with force provided by muscle, which creates an action and reaction effect and enables movement in opposite directions.

In this case, the light arm moves fast and heavy body moves slowly because the same amount of force is at work.

What will happen if you swing and cross both arms as in Figure 2? The body does not move. You will also notice that both arms can be swung faster and more powerfully than a single arm. Note that the same principles are involved in clapping hands.

First, move a single hand. You will find the motion difficult to perform because the body sways. Next, clap your hands: your body is more stable, and you can swing your hands much more quickly. This is because your hands or arms are forcefully interacting.

There is no direct interaction between both arms in a strict sense; but in various sports movements, they are, without doubt, inseparably related with each other. Since it would be cumbersome and confusing to always take the body between the arms into account, we have devised a simplified model to indicate the direct interactions of both arms (See the Figure on page 33).

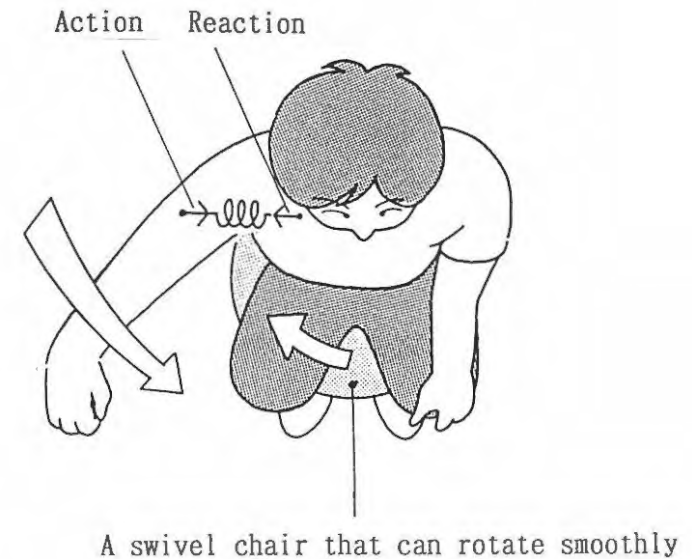


Figure 1: The mechanism of movements of an arm and a body in the opposite directions.

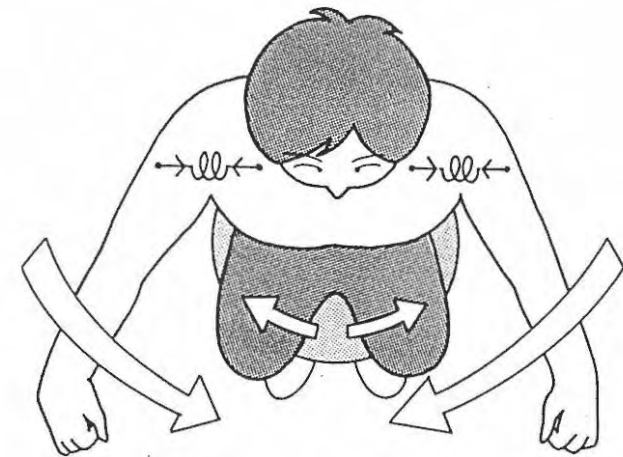


Figure 2: What if both arms are simultaneously moved and crossed?

8. Arms are helping each other !

Now, let's look into the movement of opening both arms with a simplified model as shown in Figure 1. Suppose we spring open the two rods, with the same weight attached to each tip.

The same amount of force from the release of the springs works on the two rods which rotate in opposite directions at the same velocity. Of course, in this case, the rotation refers to rotation angles, which indicate how far the arms are opened.

As it turns out, this phenomenon is similar to that of two persons on different boats pushing away each other at the same velocity, causing separation by "action and reaction". In this case, pushing the same spot in the opposite directions leads to a rotary motion.

When we compare this model to the movements of human arms, the springs of Figure 1, if placed a little closer to the center, can be regarded as muscles. Also, since the two arms, when crossed in front of the body, create a strong interactive force and help each other, this model can be applied for both repulsion and attraction.

In the case of sports that use both arms, such as tennis, the arms' lengths and weights are not always the same since players hold rackets or bend their arms.

Figure 2 illustrates the case in which a player holds something heavy; Figure 3 is a player not only holding a heavy item in his hand, but also bending his arm.

In any case, all sports movements, if regarded as pushing each other in the opposite directions, can be explained by the fundamental "action and reaction" relationship.

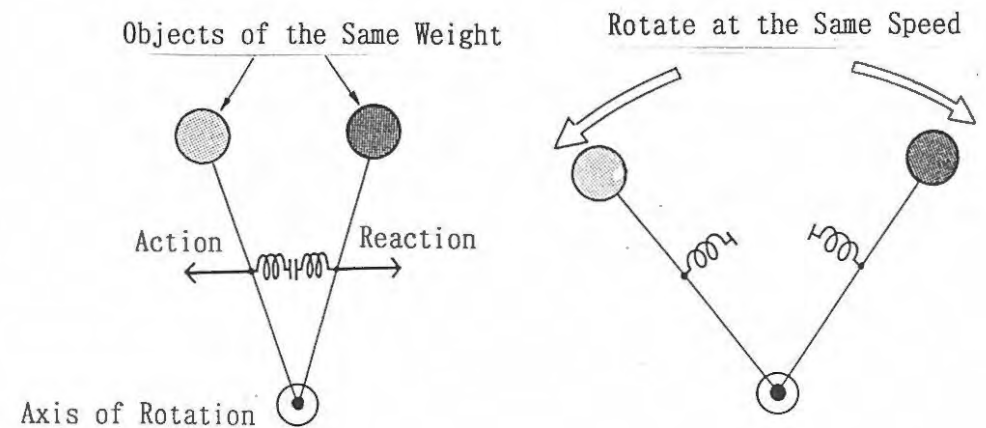


Figure 1: A model for opening arms

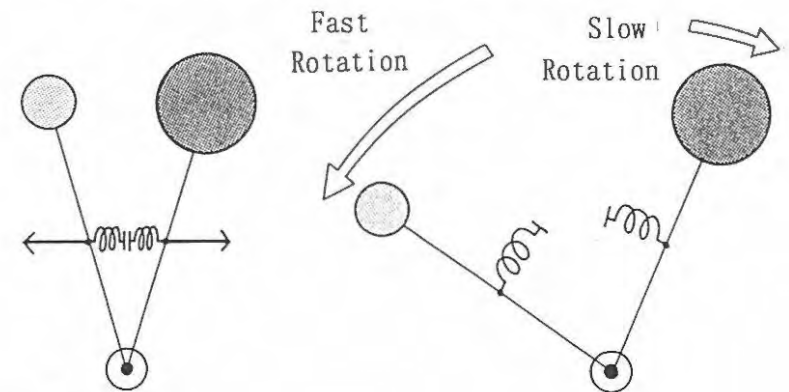


Figure 2: A model for opening arms with a weight in one hand

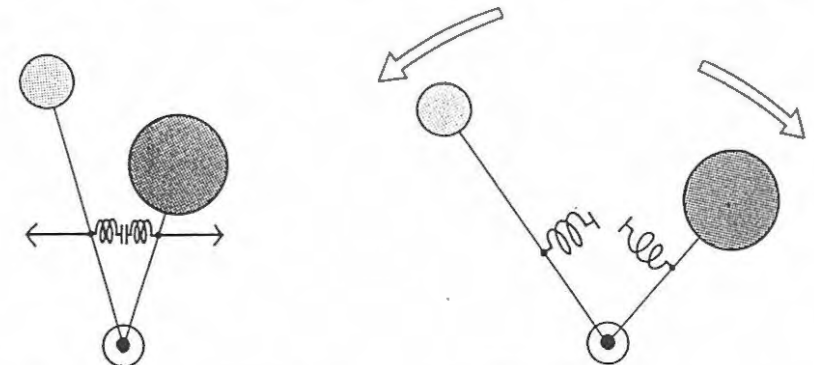


Figure 3: A model for bending the arm with the weight (Keeping the arm closer to the body for a longer time accelerates movement.)

9. A nice shot with open arms!

When rotating an arm, we do not always use the reaction of the other arm. Rather, as will be discussed later, we use the effects of twisting the body and turning the head. Still, if you want to move your arm faster and with more force, it is essential to utilize the other arm. By so doing, you will be able to achieve better balance and reduce swaying of the body. This explains why many sports try to maximize the effects of action and reaction.

Let's take tennis as an example.

Figure 1 shows the backhandstroke of a tennis player. She hits a ball with open arms. The stroke and the ball does not seem to have enough power.

On the other hand, Figure 2 shows a typical backhand of top-ranking players. To accelerate the right hand holding the racket, the left arm is swung to the back of the body. In addition, in order to swing the racket upward, the left hand is lowered. Because the left hand is swung to the back, the whole body maintains a sound balance, and generates additional power. Left leg movement behind the pivot leg has the same effect.

Capitalizing on the reaction of the left hand and the effects of action and reaction, these players demonstrate peak performance. We, as ordinary players, can surely improve our own performance by actively and effectively utilizing this principle.

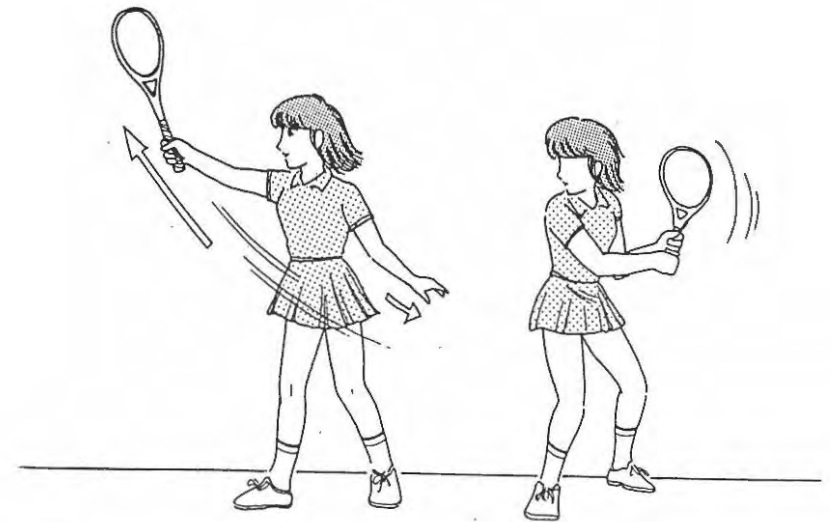


Figure 1: A backhand stroke in tennis (Without pulling back the left arm, the stroke lacks power.)



Figure 2: A strong backhand (involving not only the left arm but, amazingly, even the left leg)

10. Arms and legs help each other ?

As we have seen, opening and closing both arms quickly can be viewed as a motion of action and reaction. But if we look closely at walking, we can see that both arms and legs cross each other individually. (Figure 1)

It is difficult to walk and maintain balance with only one arm swinging. It is also difficult to walk while only bending one knee, keeping the other straight. When we walk briskly or run, bending elbows and knees, we are crossing them each other.

In Figure 2, only the forearms are crossing, with the elbows as pivots. In Figure 3, both arms are crossing, with the shoulder joint as pivots. In each case, the action and reaction effects can be felt independently.

Figure 4 shows the ordinary swinging motion of both arms, which includes the motions of Figures 2 and 3. In this case, the effects of action and reaction can also be perceived independently.

As shown in Figure 5, we run by bending and moving both arms and legs. In this case, the same principle is working on the upper and the lower parts of the legs independently. Try to move your arms and legs and perceive these effects for yourself.

As we have observed in this section, both arms and legs utilize the effects of action and reaction independently; hands and feet also are independently involved in action and reaction relationships. This point will be pursued further on page 62.

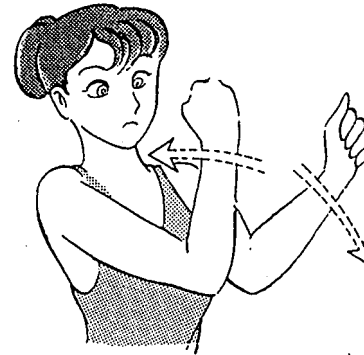


Figure 2: Crossing of only forearms

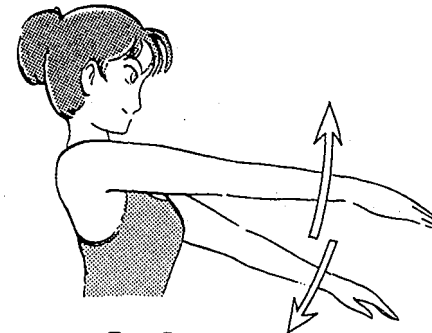


Figure 3: Crossing of both arms

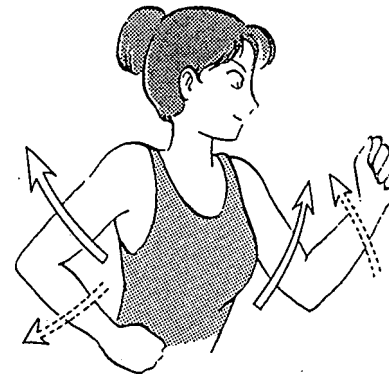


Figure 4: Swinging of both arms

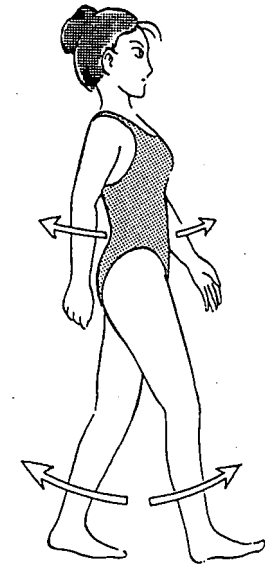


Figure 1: Walking motion

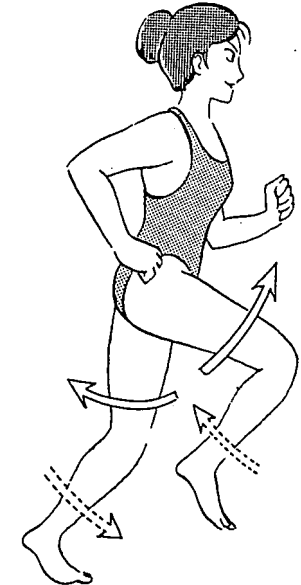


Figure 5: Running motion

11. "Action-reaction" also works between the arms and the head?

So far we have examined the case of crossing both arms, but how about moving them at the same time ?

Let's look at the motion shown in Figure 1: moving both arms up and down quickly. First try it while empty-handed. If the effect is not clear, move your arms up and down with dumbbells or other objects in your hands. You will notice that the movements of your neck or head facilitate your arm movements.

When you lower the weights, you lean back; when you raise them, your head leans forward and is pulled closer to your arms.

This time, both arms move simultaneously and do not cause any effect of action and reaction on each other. But your arms and head are attracted and repelled in accordance with the relationship of action and reaction.

This is also observed in kendo, the swinging up and down a bamboo sword, or in simply swinging any stick (Figure 2). When your motions are slow, the effect cannot be clearly perceived; but the effect is unmistakable when you try to deliver an effective blow to your opponent's head, for example. This phenomenon can be viewed as the result of action and reaction of your head and arms, with the area around the neck as the pivot.

Figure 3 shows the motions involved in moving arms up and down with the shoulders rotating. If you lean your head in the direction opposite to arm movement and utilize the effects of action and reaction, you can move your shoulders smoothly. This kind of movements is used for tennis serves.

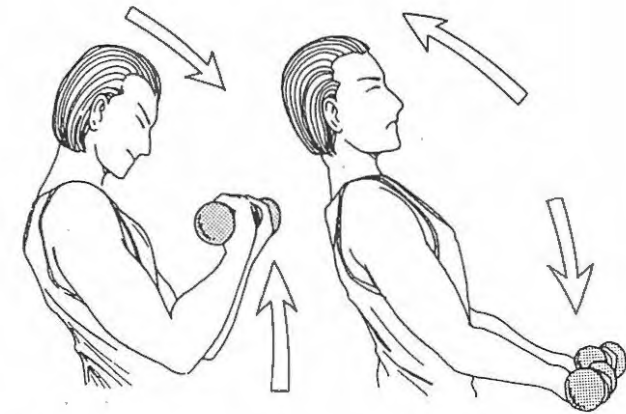


Figure 1: What is necessary for moving arms up and down quickly?

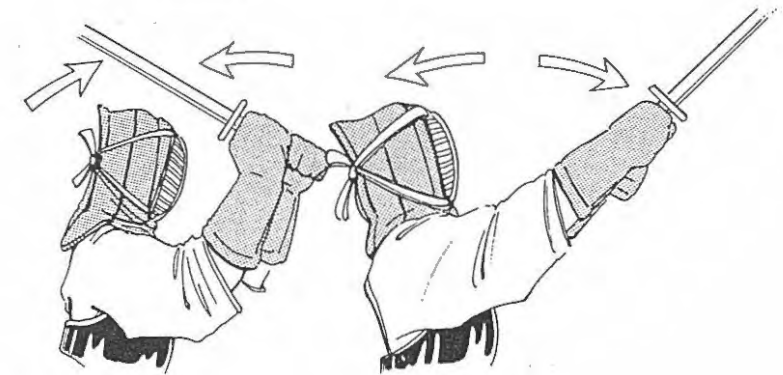


Figure 2: Delivering an effective blow on head in kendo (With the help of your head, you can score.)

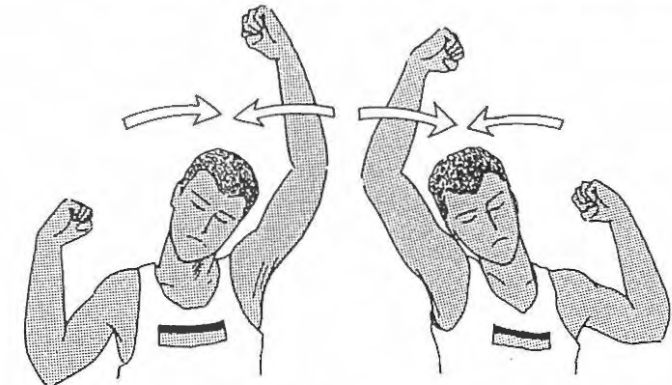


Figure 3: Rotation of the shoulders and neck involve action and reaction effects.

Chapter 3

Sports Movements: Horizontal Rotation

Quiz: Two rotors: in which direction does each rotate ?

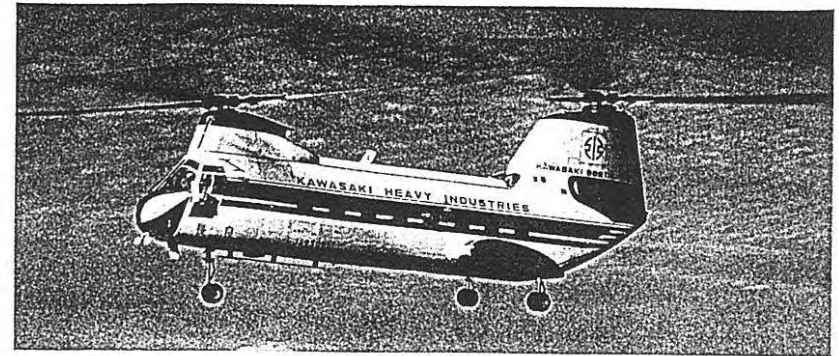
Q: Let's think about rotary bodily movements using the analogy of the principles of a helicopter. Imagine a helicopter with two rotors (Picture 1). Do they rotate in the same direction or in the opposite directions? You might intuitively surmise that the helicopter will maintain a better balance if the rotors turn in opposite directions.

A: That is right. The answer is that the rotors turn in opposite directions. Let's consider the principles involved.

First, we will take a look at a single rotor, as shown in Figure 1. By turning a rotor that is placed on a turntable able to rotate smoothly, the turntable will rotate in the opposite direction. This situation can be compared to the one in which a man whose weight is negligible rotates the light rotor by treading forward on heavy turntable.

This imaginary man turns the rotor quickly using the reactive force of kicking the table below. Here the principle of action and reaction is applied to rotary motion.

If translated into linear motion, the situation is like a man seated on a heavy cart who is pushing a light cart, as shown in Figure 2. In this case, the light cart will also move faster. These relationships are called the Law of Conservation of Momentum in the case of a linear motion, and the Law of Conservation of Angular Momentum for rotary motion. Since both phenomena are due to the principle of action and reaction, this book uses only the principle rather than an array of laws, to facilitate easy understanding.



Picture 1: Two rotors: in which direction does each rotate?
(courtesy of Kawasaki Heavy Industries Ltd.)

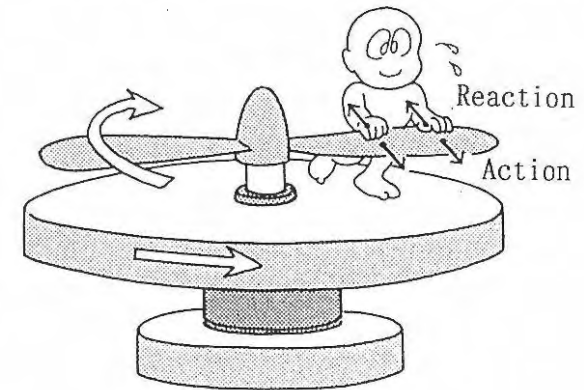


Figure 1: When the upper part is turned, the lower part moves in the opposite direction.

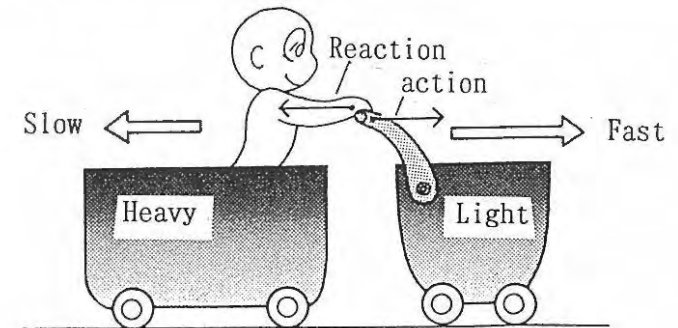


Figure 2: If you push, you are pushed back!

12. Can you rotate alone?

As indicated in the previous section, the body of a helicopter equipped with only one rotor might rotate in the opposite direction, creating a dangerous situation. That explains why an auxiliary rotor is placed on the rear end of the helicopter: to offset the rotational movement of the fuselage. (Figure 1)

The body of a single-engine propeller plane, although rare these days except in small models, also tends to rotate for the same reason. (Figure 2)

As a matter of fact, however, the angles of the long wings may be adjusted to suppress the rotation, thereby solving the problem.

When there is only a single rotor blade as shown in Figure 3, as long as it can rotate without being affected by the ground, its upper and lower parts move in opposite directions due to the principle of action and reaction.

This situation can be compared to human motion that we have already introduced: swinging one arm horizontally while sitting on a swivel chair that has negligible friction (p.28).

Another feature of rotational movements is that to provide force, two objects must act against one another; when one part turns around, the other moves in the opposite direction. In other words, "you cannot rotate alone."

In this way, if we view the human body as a composite of several factors (e.g. arms, waist, etc.) various human motions will become much easier to understand.

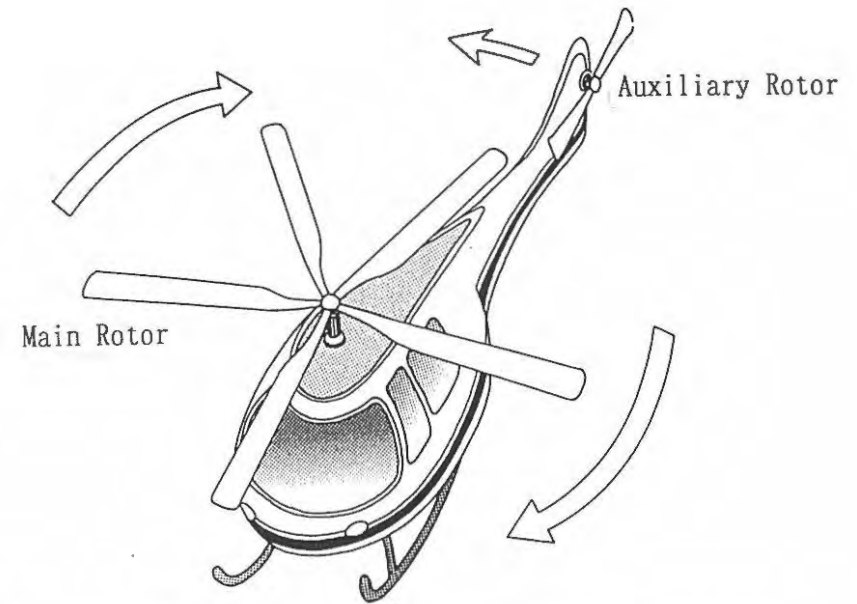


Figure 1: The auxiliary rotor of a helicopter offsets the rotation of the fuselage.

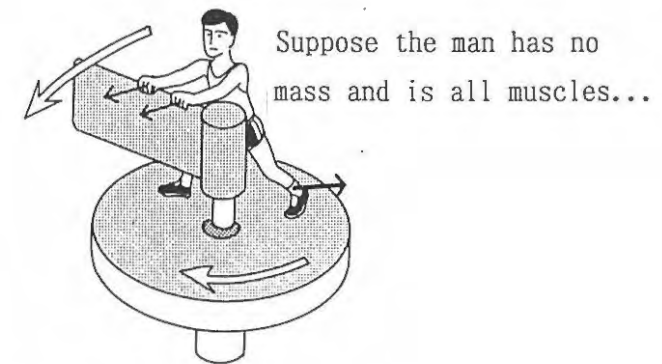
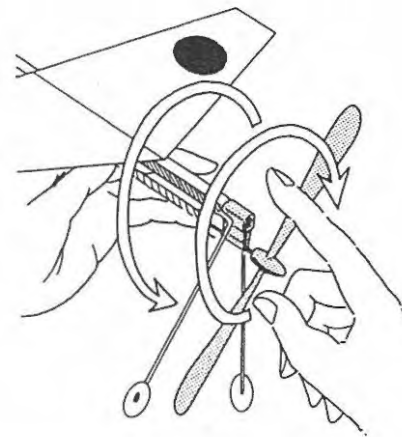


Figure 3: Rotation of a single rotor blade

Figure 2: If you turn the propeller of a rubber band-propelled model plane, the body tends to move in the opposite direction.

13. "Action and reaction" is the cause of everything!

We have so far discussed various cases of action and reaction in sports movements. It is about time to review and determine common factors.

Sports movements can be generally divided into linear motion and rotary motion. For each, this section introduces the concept of "separation phenomenon".

As indicated in Figure 1, rotary motions are divided into two types: first, when only arm movements occur, and second, a general case which includes twisting the body while jumping.


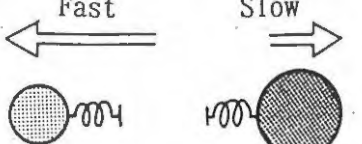
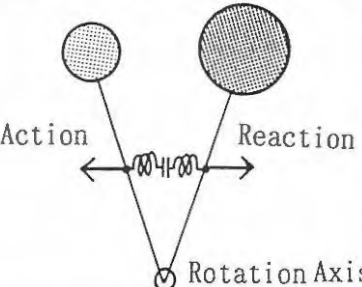
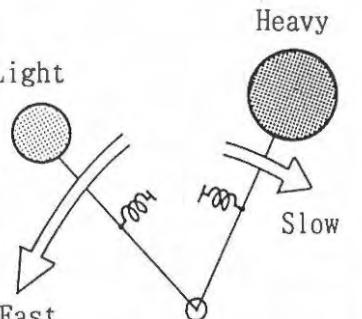
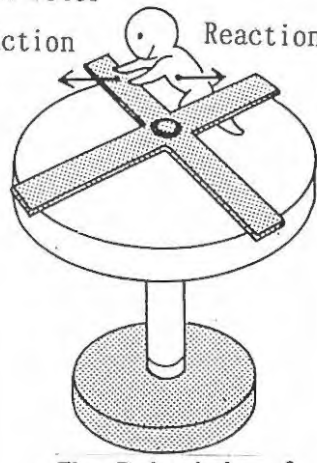
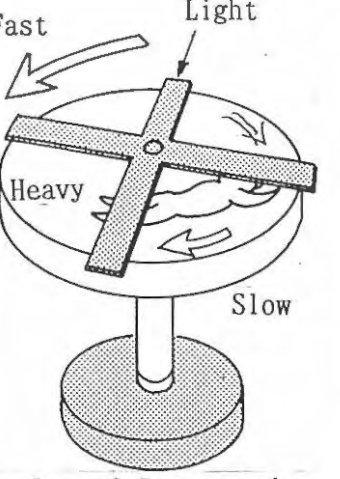
In these cases, two objects first separate from each other, illustrating the action and reaction relationship. Since both objects move with the same amount of momentum, it will always be true that a light object moves fast while a heavy one moves slowly.

These phenomena are caused by the force derived from action and reaction, but we are generally unaware of it, so we get confused and seem to end up with complicated arguments. Some even voice doubt whether concepts of dynamics in sports movements are effective for improving sports techniques.

What we attempt in this book, therefore, is to qualitatively analyze all sports movements in accordance with the principle of action and reaction, in order to demonstrate to the reader the role of action and reaction in such movements.

It is not too late to think about detailed explanations afterward.

<Common factors of sports movements>

		Cause (pushing with the same amount of force)	Result (achieving the same amount of momentum)
Linear Motion		Repelled by light springs Action Reaction  The Principle of Action and Reaction	Fast Slow  Light Heavy The Law of Conservation of Momentum
	Rotation around an Axis	Repelled by light springs Action Reaction  Rotation Axis The Principle of Action and Reaction	Light Heavy Fast Slow  The Law of Conservation of Angular Momentum
Rotary Motion		A light person pushing a rotor Action Reaction  The Principle of Action and Reaction	Fast Light Heavy Slow  The Low of Conservation of Angular Momentum
	Rotation on a Turntable		

14. Even the rotation of the head creates power!

We have already observed that when an arm is swung horizontally, the body is moved in the opposite direction. What will happen if we rotate the head, instead of an arm, on a turntable (Figure 1a)? Amazingly, the body turns in the opposite direction! Here the relationship of action and reaction derived from rotary movement also exists between the head and the body. Furthermore, if we turn an arm and the head in the opposite directions, as in Figure 1b, the forces cancel out and prevent the body from rotating.

Let's take a look at an example of an actual sports movement: a volley in tennis (Figure 2). Imagine a fierce rally of volleys. There is no time to go into a backstroke or swing the racket with the upper body leaning back.

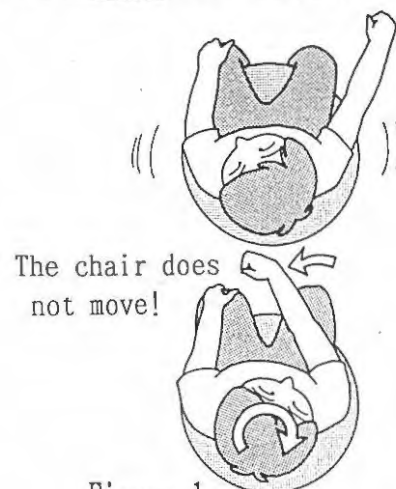
For volleying, you need only to make contact between the ball and the surface of the racket at the appropriate angle. But merely returning the ball might offer your opponent an easy ball to return or a chance to hit an effective passing shot. Thus, you must volley the ball as forcefully as possible.

This is where head rotation becomes important. Using the reaction of the head's rotation toward the right, you can rotate your right arm slightly to the left with additional power, which may lead to an ace.

Also, when you have enough time, you can substantially rotate your head past your shoulders to hit an effective volley (Figure 3). Because the head is quite heavy, even the slight movement can be very effective.

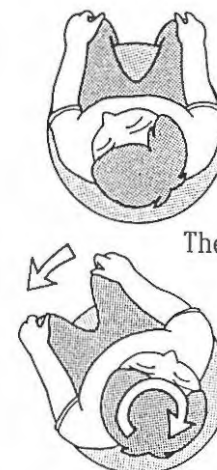
In addition to tennis, we use the rotation of the head almost unconsciously in many sports. If a quick movement is required, in particular, conscious use of this movement can be quite effective.

b. If you move the head and the right arm in the opposite directions,...



The chair does not move!

a. If you swing your head,...



The chair turns around!

Figure 1: Experiments on a swivel chair

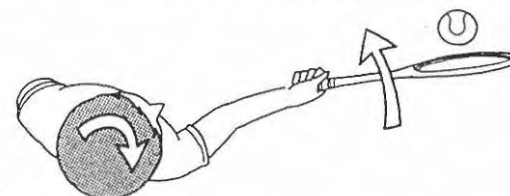


Figure 2: A volley utilizing the turn of the head

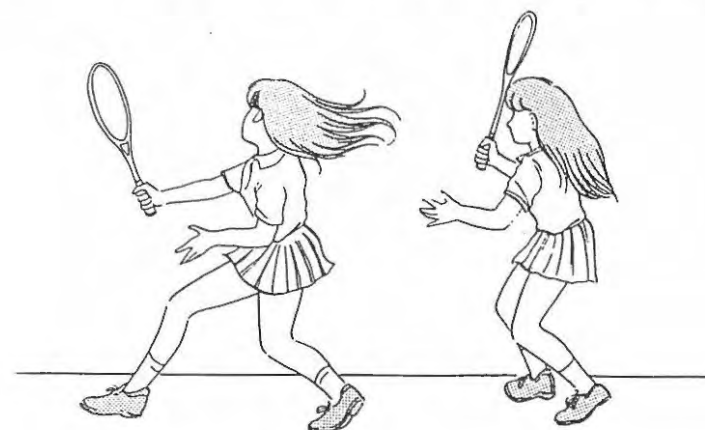


Figure 3: A forehand volley in tennis

15. Is head rotation also effective in golf?

In golf lessons, a piece of advice we often hear is "Don't move your head." (Figure 1) How many amateur or professional golfers have been misled and troubled by this rather ambiguous advice!

It is also frequently taught that at the moment of impact after returning the body from the twisted posture, only club momentum is at work, and that no other force is involved.

But that is not the case. At the moment of impact, additional forces are also employed.

Take head rotation as an example. The head's clockwise rotation creates a reactive force that can strengthen the rotary motion of the arms.

Professional golfers frequently advise that the head should be adequately turned. This twisted posture cannot be achieved merely by tilting the head. Rather, the head must be substantially turned.

Other factors are also involved in increasing the power of a golf swing immediately before and after an impact, such as tilting back of the upper body. The reactive force derived from these factors, together with the forward motion of the club, will produce a powerful swing.

In short, golf players improve accuracy and hit long drives by capitalizing on the principle of action and reaction.

Even in a small swing as shown in Figure 2, rotation of the head is effectively used to improve directional accuracy and bodily balance, as well as to avoid "hitting behind the ball."



Figure 1: A shot in golf... the head should be actively rotated to produce more power.



Figure 2: An approach in golf... the rotation of the head is even more effective because the overall bodily movement is minimal.

16. Skiing also uses "action-reaction" ?

We have seen how the fuselage of a helicopter tends to move in the direction opposite to rotor rotation. Similar movement can be observed in various sports movements.

Suppose you try to swing a bat on a round table that can rotate freely (Figure 1). Your body moves in the opposite direction to your twisting motion. Thus, swinging the bat with full force is not very effective.

This experiment demonstrates that we usually swing a bat by utilizing the reaction derived from frictional resistance to the ground. In other words, turning or jumping on a swivel chair uses the same principle as the movements of the helicopter rotor and fuselage.

Similarly, consider jumping and twisting the body in the air, as seen in creative dancing or gymnastics (Figure 2). When the upper part of the body turns clockwise, the lower part has to move counterclockwise. This phenomenon is another example of action and reaction working with rotary motion.

The same principle works in skiing and skating, when friction with the ground (covered by snow and ice) is minimal. Consider a common skiing technique, the "jump turn", which utilizes twisting of the upper and lower parts of the body while jumping and lifting the rear ends of the skis. Although the skis do not exactly lift off the snow surface, a skier can initiate a turn by so-called "shifting weight".

Particularly in case of the "wedeln" technique, which involves the rhythmic swinging of the rears of the skis, this principle is frequently applied to initiate quick turns. "Jump wedeln" fully utilizes weight shifting as well (Figure 3).



Figure 1: If you swing a bat on turntable,...



Figure 2: Jumping and twisting the body



The rotary motion of the extended arms and poles (making use of the moment of inertia) is very effective.

The upper part of the body turns due to the horizontal rotation of the skier's arms and poles. Direction of the face and chest is unchanged. Active arm swinging will enable quick turns!

Figure 3: A jump wedeln turn

17. Skating also uses "action-reaction"?

In order to stop in skiing, the upper body turns sideways and both skis dig into the snow surface (Figure 1).

The same method is used for stops in ice skating, with similar body movements and both feet kept in parallel (Figure 2).

When we try to return the twisted body to a normal posture, motion in the direction opposite of twisting must naturally occur. At this moment, since the twisted posture retains potential energy, this untwisting motion can be easily accomplished if the principle of action and reaction is fully utilized.

Figure 3 depicts a skating turn called a "double-leg three-point-turn", which is executed by turning the body in the direction opposite to the direction of skating. In this case, the twisted body returns to normal posture during a small jump. A strong kick against the ice surface turns the body at 180 degrees.

This forceful kick is enabled by the effective utilization of the potential energy of the twisted body. Similar movements are also used in skiing.

In any case, these sports movements are much easier to understand by thinking of them as motions that utilize rotary action and reaction.

Horizontal rotation discussed in this section can be easily understood by dividing the athlete's body into two parts (e.g. arms and torso; head and torso; and upper body and lower body).

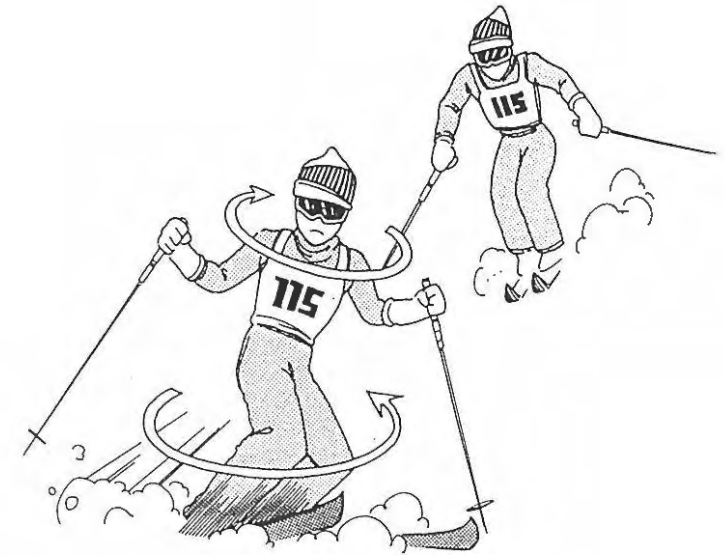


Figure 1: A quick stop while skiing (Bend the knees quickly; when you feel a slight lift, twist your upper and lower bodies in opposite directions and stop with the edges of your skis.)

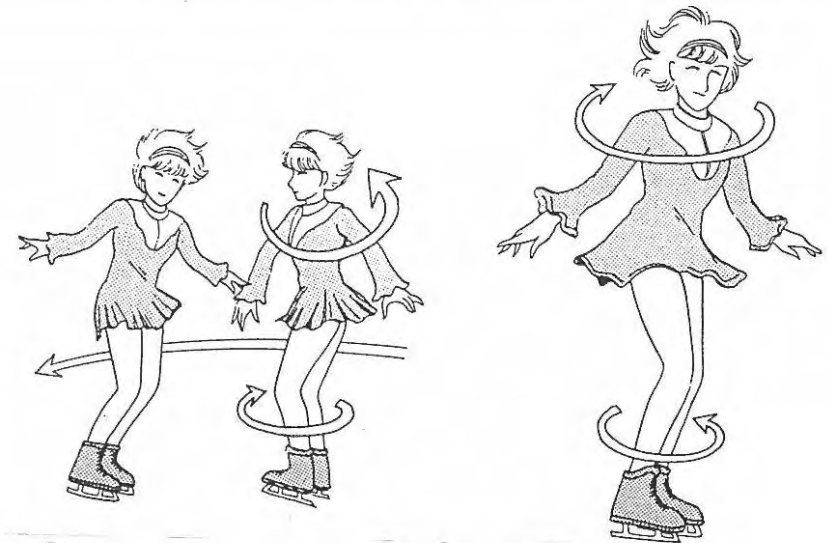


Figure 3: A "double-leg three-point-turn" in skating,

Figure 2: A "parallel-blade stop" in skating

18. What is the model for hitting a ball with a twisted body?

So far, we have considered various types of rotary action and reaction. The model for understanding all of these movements is based on separation of the body into the upper and lower sections, as shown in Figure 1a, and it is an example of action and reaction for twisting the upper and lower parts in opposite directions. This model makes such sports movements easy to understand.

What kind of model will describe hitting a golfball or base ball a great distance, using recovery of a twisted body and firmly planted feet?

First, as in Figure 1a, we will consider a model separated into two parts: the upper and lower parts of the body (Figure 1b). Try to move your body; can you feel the effects for yourself? In Figure 1b, the upper and lower parts of a body are twisted in the same direction, since the feet are planted on the ground. In this case, the ground is providing the twisting force in the opposite direction to the turning body.

This situation is a bit more complicated to envision, since three different forces are working on this body. Focusing on the upper and lower body parts twisted in the same direction, we have devised a model, shown in Figure 1c. In this model, the upper and lower forces represented by (1) and (2) are unified and regarded as a single sum force. Now it is possible to view the situation as having only the two forces of action and reaction between the upper and lower parts of a body, just as in our previous model.

To further understand the concept of a twisted body, consider the model of a twisted rubber strip as shown in Figure 2.

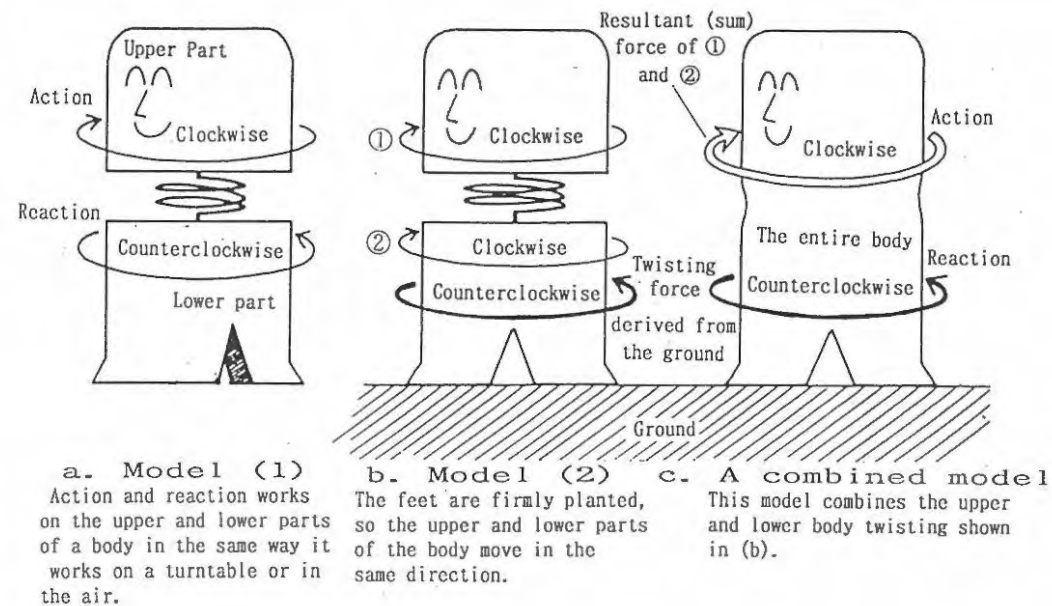
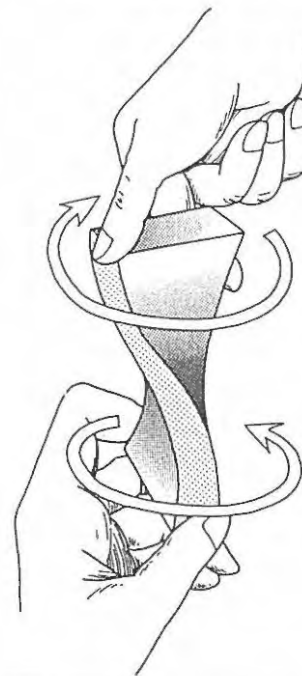


Figure 1: Which model should be used for a twisted body (with the upper body twisted in a clockwise direction)?



Muscles are used to twist the upper body (as if the force were applied from an external source).

The lower body is fixed, due to friction with the ground.

Figure 2: Model comparing the body to a rubber strip:

19. Little power is derived unless the twisting is accompanied by "action-reaction"!

This section investigates how we create power when swinging a golf club or a baseball bat.

First, no force can exist by itself; it must work in pairs according to the principle of action and reaction.

Figure 1 shows twisting motion of the body, which can be regarded as the twisting of a single object by two horizontal forces working on the upper and lower portions of a body (also shown in Figure 2 of the last section).

Viewed in this way, muscles turn the upper body, and the lower body is subjected to a force in the opposite direction. These two forces are an example of action and reaction; because they pull against one another, a forceful twisting motion is possible.

However, if the knee is slackened, it will not maintain its rotary momentum, making it difficult to both twist the body and to return from a twisted to a normal posture.

The same situation applies to golf swings (Figure 2) and swinging a bat in baseball. A powerful swing makes the most of thereactive momentum derived from the ground.

Actual sports movements are characterized by kicking the ground and shifting weight, as shown in the second stage of Figure 2. This enables a continuous counterclockwise rotation (in the case of a right-handed player) immediately after the clockwise movement.

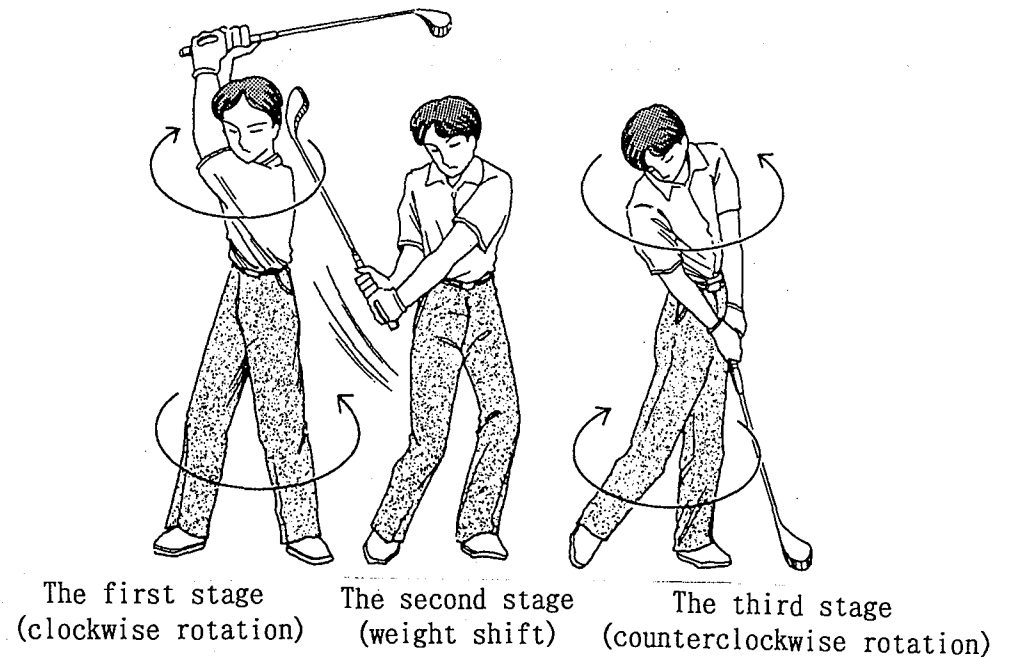
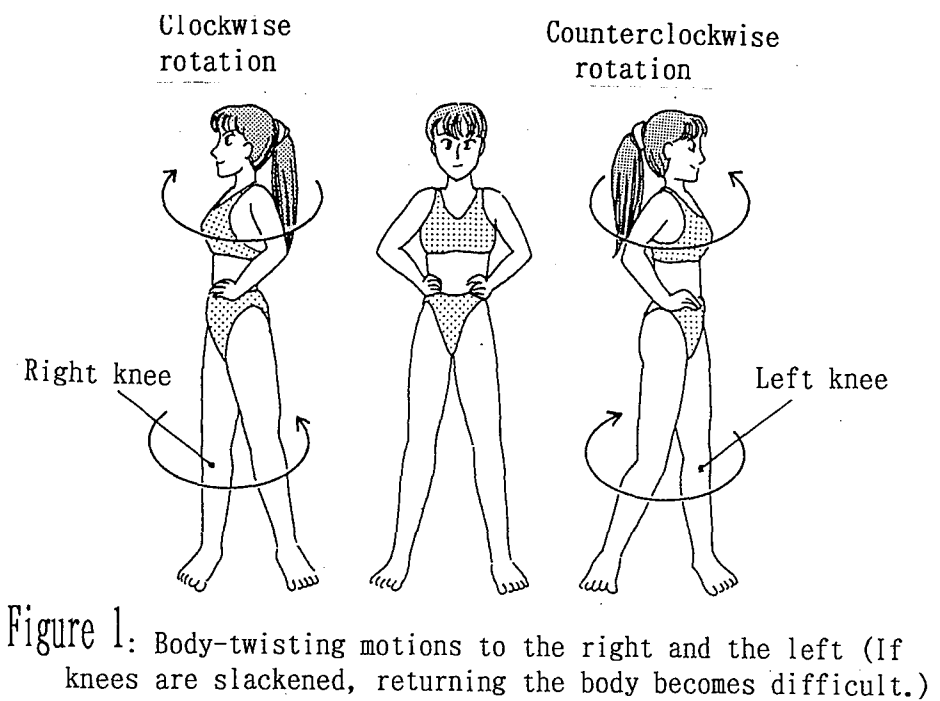


Figure 2: Action and reaction in a golf swing

20. Is twisting the body the same as twisting a spring?

Muscular strength is often compared to a spring or a rubber strip, as indicated by the phrase, "spring-like movement". This comparison is instructive for our discussion because it involves an important point, discussed below.

Figure 1 shows the top-of-the-swing position after maximum twisting of the body. Even the wrinkles in this golfer's shirt make the golfer appear as if his whole body is about to spring back in the opposite direction. In actuality, if the twisting power is released at this moment, the body will hardly move in the opposite direction. It is often said that the spring-like power derived from twisting the body will lead to a long drive; what has happened to it?

The answer involves muscle functioning: that is, muscles only produce power during contraction, whereas a spring produces power during both contraction and release.

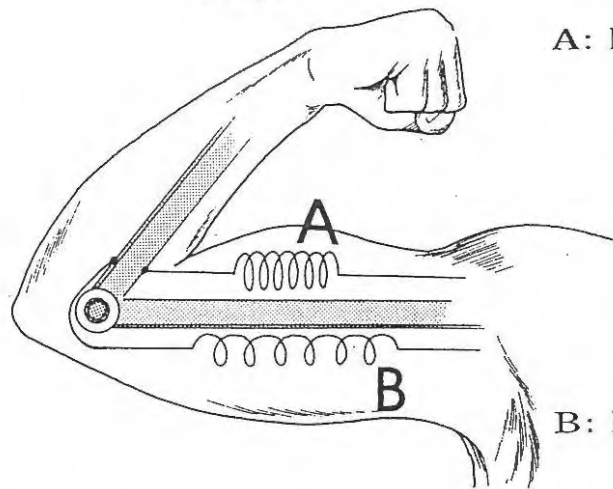
Figure 2 shows the roles of various arm muscles, whose resulting power is generally used to twist the torso. As is evident from the Figure, two sets of muscles are used to twist the body and to return it to its original position.

When twisting the body, the muscles involved actually work to maximize extension of the muscles used to return the body, in preparation of untwisting. For returning the twisted body, therefore, a second set of muscles is employed.

Without such knowledge, you might think that a twisted body, like a spring, can release 100% of energy "stored" in twist position. Such a misunderstanding might lead you to twist your body to an unnecessary extent.



Figure 1: Is "twisting the body" the same as twisting a rubber strip?



A: Muscles that contract the arm
When A muscles contract,
B muscles relax.

If you try to simultaneously contract both A and B muscles, you will be in an "unnecessarily strained" state. You cannot move your arm smoothly without the contraction/relaxation trade off between the two sets of muscles.

B: Muscles that extend the arm
When B muscles contract,
A muscles relax.

Figure 2: Different muscles are used to bend and extend an arm. ... Since maximum achievable power is only about one third of maximum muscle strength. Thus, you do not have to exert enormous strength to maximize the power of your swing.

21. Watch out! To prevent falling, why do you swing your arms?

This is a scene from a TV cartoon program (Figure 1). The hero is desperately trying to prevent himself from falling by waving his arms. And what a relief! He didn't fall.

But such motions are not limited to the world of cartoons; we all use arm-waving to regain our balance, even without realizing that we are doing it. These motions move the body in the direction away from falling by using rotary action and reaction.

So far, we have considered horizontal rotary motions. The same principles can be applied to vertical rotary motion.

Such motions are observed in actual sports movements.

Figure 2 shows body position immediately after the finish of a shot put motion. Even in successful delivery, if the player loses his balance and oversteps the line, the shot will be judged as a foul. This situation requires arm swinging to regain balance.

Think also of the gymnast who rotates her arms to establish her balance when landing after executing a movement.

Arm rotating is also used to maintain posture, and to gain momentum to launch the body forward.

Figure 3 shows a start in swimming where both of the swimmer's arms are swinging; this is an instructive example of the concept presented in this section.

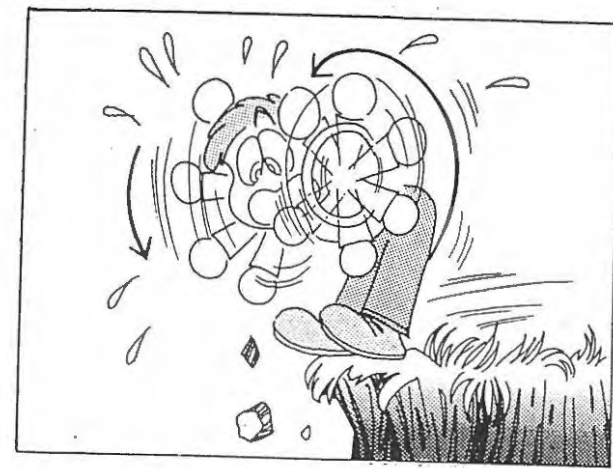


Figure 1: Watch out! Don't fall off the cliff...
what can be done?



The finish in a shot put throw.
(also for discus, hammer,
or javelin throws)

Figure 2: What should you do if you lose your balance
after throwing?

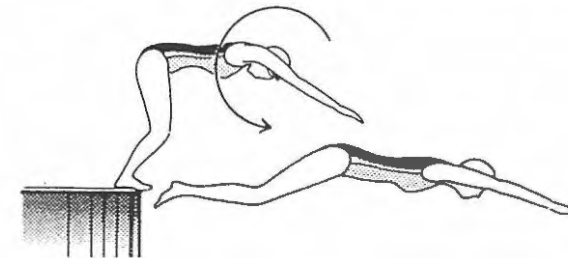


Figure 3: A swimming start that uses arm swinging
(a beginner-level jumping start)

22. Is swimming the same as running?

Competitive swimming involves skimming through the water as fast as possible. The swimmer is propelled by the force of arm strokes and leg kicks. In this section, we will examine these movements in terms of concepts of action and reaction around a pivot.

The freestyle stroke in Figure 1 and the backstroke in Figure 2 both use alternate motions of legs and arms. It's not hard to imagine action and reaction at work here.

A closer look reveals that the upper and lower sections of the body are twisted in opposite directions, suggesting that interaction between the arms and legs is involved in action and reaction.

For example, if you view the movement of a freestyle stroke from behind, it looks like the diagram in Figure 3. From the side, the whole movement seems to entail only alternate arm and leg movement, but it actually constitutes a type of rotar motion. The legs rotate in the direction opposite to the hips, which are somewhat controlled by movement of the upper body.

In Figure 3, leg kicking produces force in the clockwise direction and arm strokes produce a counterclockwise force, thus enabling action and reaction. This generates the power necessary to propel forward through the water. Backstroke uses the same principle, except that the body faces the opposite direction.

As noted on page 36, arm swinging and leg movement in running are interrelated. As a matter of fact, the same is true for swimming: the upper and lower sections of the body twist in opposite directions, just as in running (Figure 4).

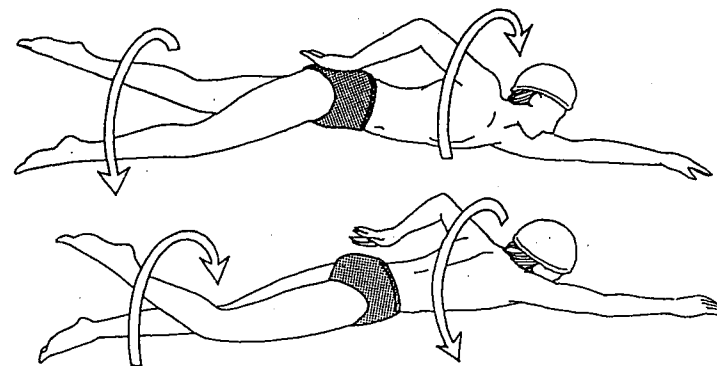


Figure 1: Freestyle (What is meant by "Swim as if you are running"?)

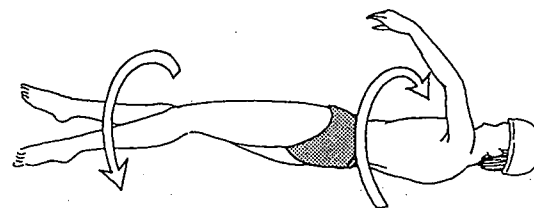


Figure 2: Backstroke

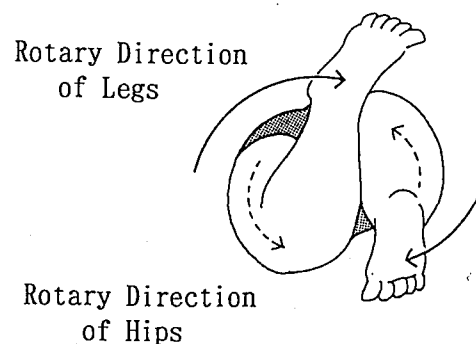


Figure 3: Leg and hip movements in freestyle

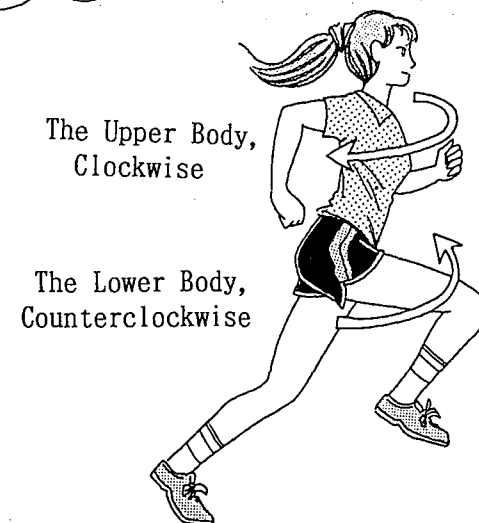


Figure 4: The body twists while running full-speed in a race

Chapter 4

Sports Movements: Using the Laws of Gravity

Quiz: Make haste slowly...
can you go faster
by taking a roundabout way?

Q: Suppose two roller coasters, A and B, start at the same time from the right end and run on the two different courses. Which do you think will reach the finish first?

Although train B accelerates on the second downhill, it will decelerate going up the last hill. Thus, A and B will reach the finish at the same time....

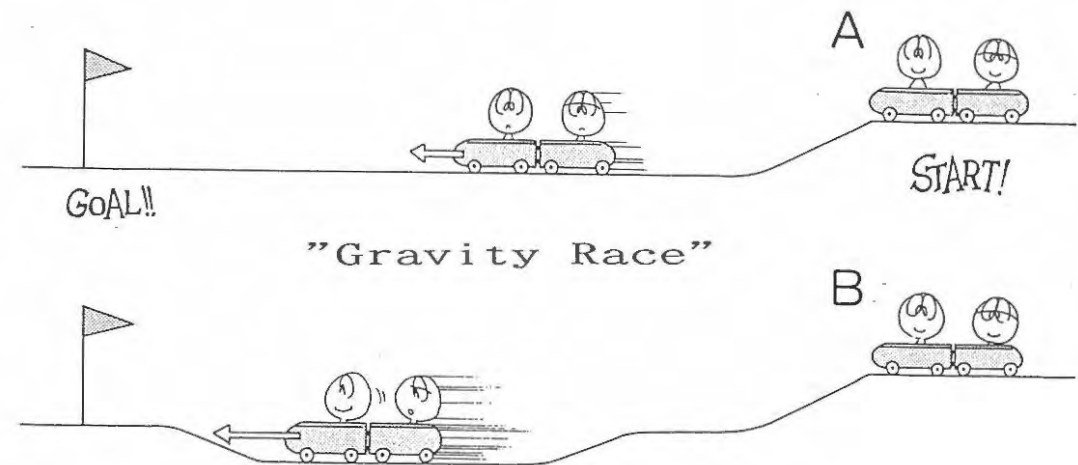
A: ...You might reason that way, but the answer is that B, accelerated on the downhill, will travel through the flat part faster than A and reach the finish before A. Why does this happen?

The answer is gravity. When roller coasters go downhill, they get accelerated due to the force of gravity. In other words, gravity is the unseen player here.

This principle is used for glider races, a sport utilizing no propelling power source. This explains the effectiveness of descending once to go ahead of the others, and then ascending to maintain an adequate altitude. Rapid transit subway trains also make use of this principle. As you can see, acceleration created by gravity can be utilized in many different ways.

Naturally, gravity plays an important role in sports movements. In this chapter, we will discuss topics related to this principle.

Which gets to the finish first?



23. Why toss a ball underhand when the target is nearby?

When we throw a ball to a nearby target, why do we toss it underhand (Figure 1)? Possibly because an overhand throw may be too fast, and therefore dangerous. This is certainly a good reason, but think about it from the standpoint of gravity.

Have you heard the term, "potential energy"? In short, it is the amount of energy that an object placed in a high position possesses.

Hydraulic power generation utilizes potential energy. When water stored in a dam flows from the top of the dam downwards through the water mill (making use of the gravity), turbines are turned to produce electricity.

The same principle is evident when dropping a ball from your hand, as in Figure 2. The ball gets accelerated as it travels, because its potential energy is transformed into "kinetic energy."

The higher an object's original placement, the greater the resulting acceleration. The weight of the ball is insignificant; on the other hand, the weight of the arm swung in a big circle is important (the weight of an arm of a grown male is about three kilograms).

If you throw a ball underhand, the gravity is nearly opposite in direction to the throwing direction, thus reducing the ball's acceleration.

When we throw an object, we use both our muscles and gravity, almost without knowing it (Figure 3).

<In throwing, we use both muscle power and gravity.>

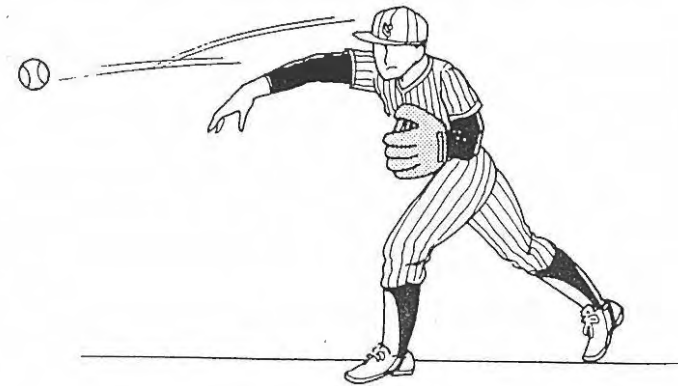


Figure 1: Why toss a ball underhand for a nearby target?

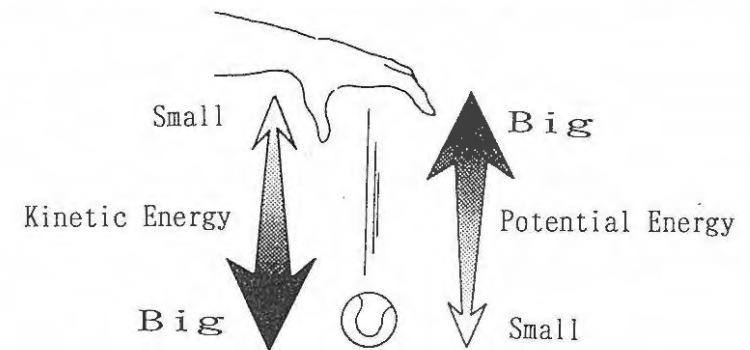
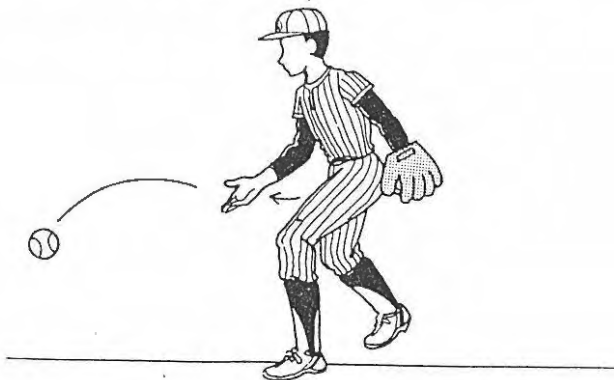


Figure 2: The higher the original placement of an object, the more it will accelerate.



32 Figure 3: We throw a ball overhand to a distant target!

24. Why is an underhand pitch thrown overhead?

As is evident in baseball (pitching) and volleyball (serving, Figure 1), when we want to throw a fast ball to a distant target, we throw it overhead; and when we want to throw a ball accurately to a nearby target, we use a underhand throw. Other examples include a goalkeeper's throw in soccer (Figure 2) and badminton serve.

In baseball, some pitchers use underhand throws (Figure 3); but their pitches are forceful and very aggressive. Why is that?

When we observe such pitches closely, it becomes clear that the ball is first held in a high position and then thrown down. This is another case of transforming the potential energy of an object at a high position to kinetic energy.

In the case of underhand throws, energy is diminished as the arm lowers, which makes a ball a little slower than a ball pitched overhead. Still, underhand pitches are capable of delivering various breaking balls, which skilled pitchers use to baffle batters.

In badminton, although a service has to be delivered from an underhand position, the racket is first held in a high position. The same is true in the underhand volleyball serve: a strong and deep serve is delivered by the momentum gained by casting down the arm from an overhead position.

Thus, it is important to adequately utilize gravity to maximize your performance potential.

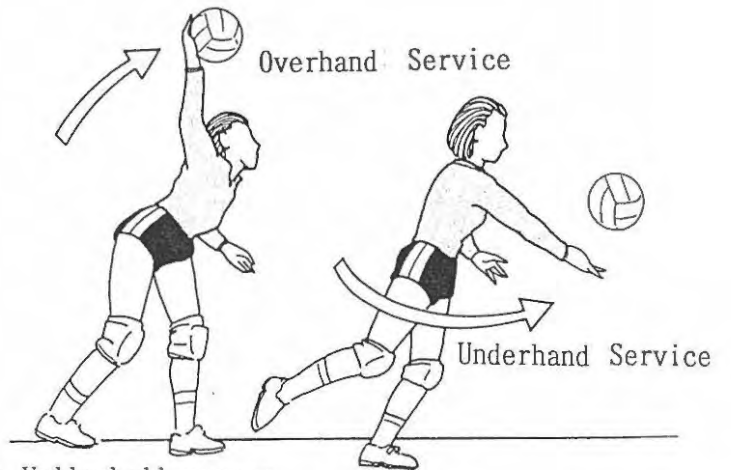


Figure 1: Volleyball serves

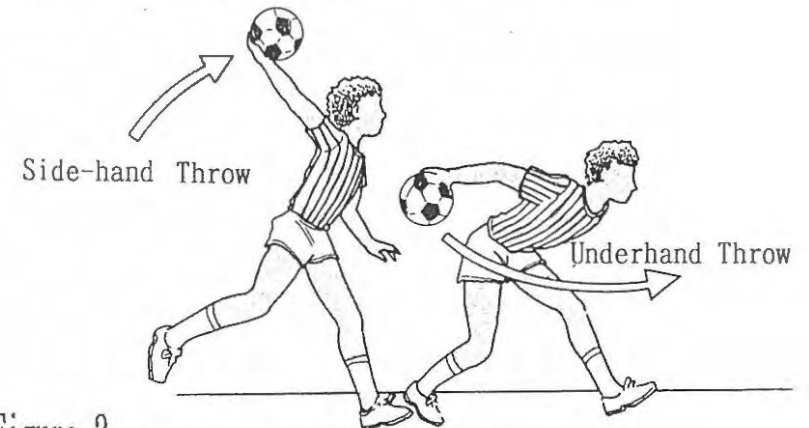


Figure 2: Goalkeeper throws in soccer



Figure 3: Underhand pitch in baseball

25. The movement of a pendulum uses gravity!

The movement of a pendulum is a repetitive motion,... an object placed at a high position descends and attains maximum velocity at its lowest point. Its momentum then raises it to the highest point on the opposite side; the object then stops, and starts falling again in the opposite direction... (Figure 1).

Let's take a look at swinging motions in tennis, baseball (batting), and golf (Figure 2). Arm and equipment movements resemble pendulum motions.

The pendulum motions in various sports movements are not due only to muscle power or gravitation; they result from optimal combinations of these two forces.

At any rate, a ball hit as fast and far as possible requires maximized impact velocity at the lowest point of the pendulum motion. This kind of sports movement maximizes kinetic energy given to the ball, and after impact, the follow-through involves swinging up one's arm or equipment.

If impact is made perfectly, a great amount of kinetic energy is smoothly transferred to the ball from the body, and the player maintains his balance, with the satisfied feeling of full contact. A "solid hit", particularly in the case of hitting of baseball, reduces the need to take a high finishing posture.

However, if the ball does not hit the "sweet spot" or if you swing and miss, the momentum created by muscle power must then be stopped using muscle power. This may cause unnatural movement after impact point, and lead to injury.

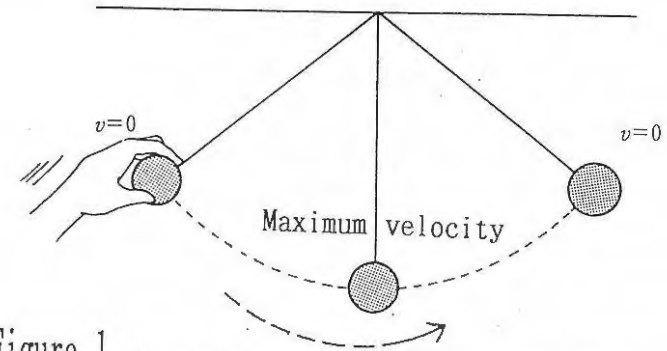


Figure 1: Pendulum motion (The maximum velocity, v , is obtained at the lowest point.)

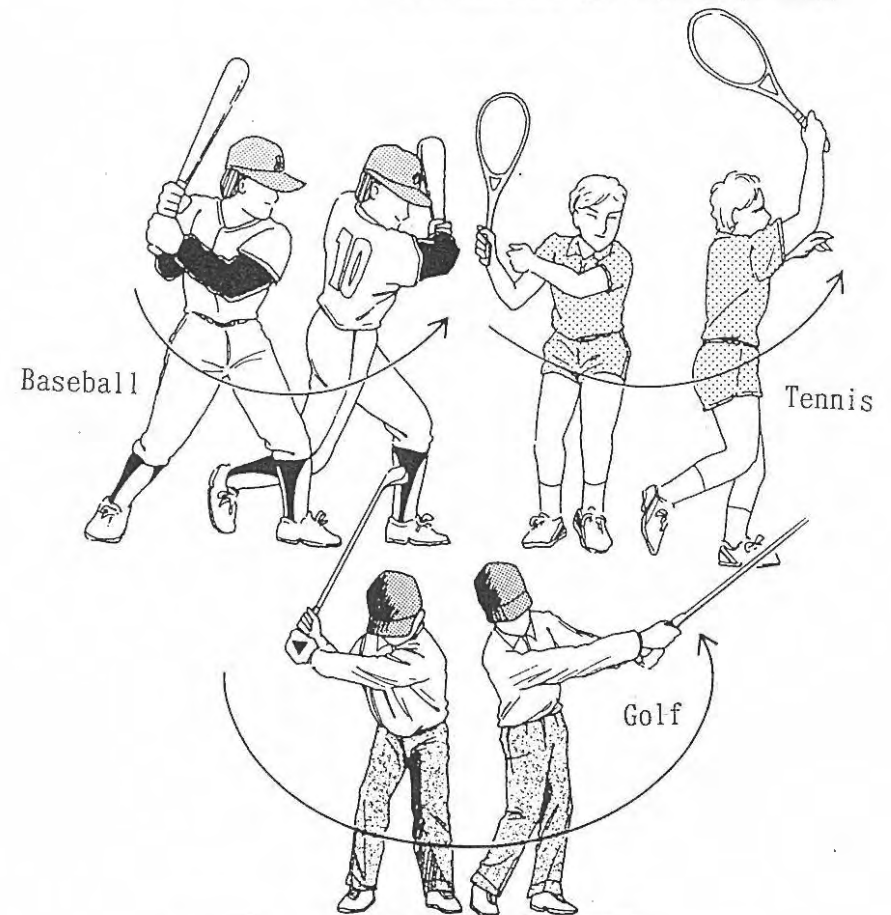


Figure 2: Swinging motions that utilize the pendulum motion

26. Squatting while skiing leads to acceleration!

An object may fall in various patterns, as indicated in Figure 1; yet in all cases, the entire potential energy at the highest point is transformed into kinetic energy at the lowest point.

During falling, the potential energy decrease is transferred into a kinetic energy increase; but all in all, the sum of both energy forms remains constant (this is called the Principle of Conservation of Mechanical Energy).

Based on this principle, let's take a look at the physical dynamics involved in skiing.

Consider Figure 2. On a steep slope, a beginner tends to lean forward in a half-squat posture, which further accelerates the sliding motion, producing so-called "skiing on rear edges".

The cause of this phenomenon can be explained this way: squatting lowers the center of gravity, reduces potential energy, increases the kinetic energy, and accelerates sliding motion. Think of competitive Alpine skiers, who usually squat immediately before the finish to eliminate that last hundredth second off their times.

As in Figure 3, it's also possible to use squatting to gain enough acceleration to move upwards on a slope.

When upward and downward body position changes, potential energy varies, which alters the kinetic energy (velocity) of the movements.

Effective use of this principle will improve your skiing performance dramatically.

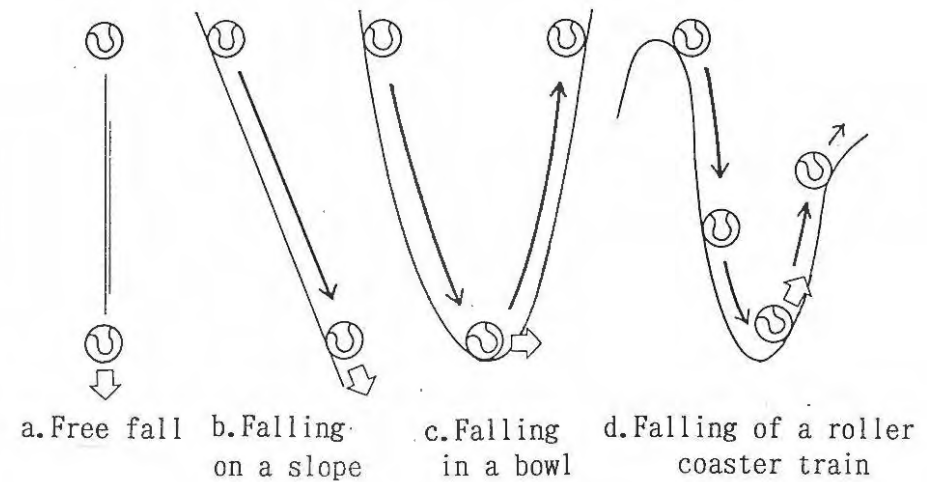


Figure 1: Various types of falling

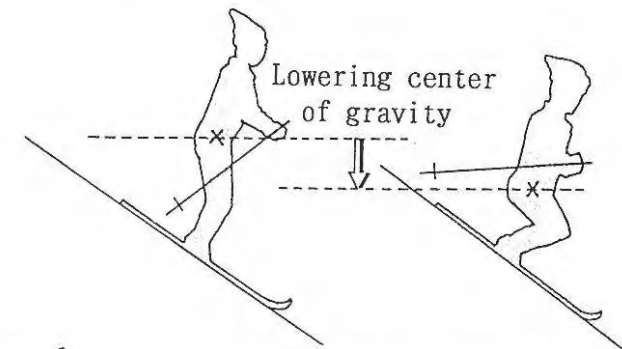


Figure 2: What if you squat on a downhill slope?

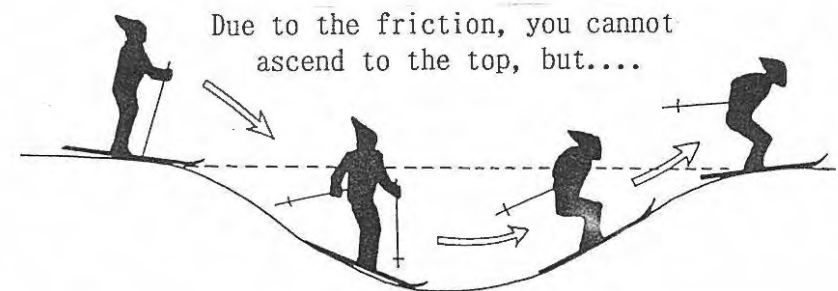


Figure 3: What if you squat to move up a slope?

27. Can you slow down any object by lifting it up ?

When sports movements are completed, part of the remaining kinetic energy will be absorbed by collision with a soft mat, bending the knees, or throwing or hitting an object. Finally, everything will reach a stationary state.

But all kinetic energy cannot be absorbed in this manner; how is the energy actually consumed?

Here we consider some concrete cases in which remaining kinetic energy is offset by elevating part or all of the body, thus increasing its potential energy.

The first example is the defensive fall in judo (Figure 1). The kinetic energy that has not been absorbed by the tatami or cushion is released by elevating both legs.

A baseball pitcher, as shown in Figure 2, releases the remaining energy after throwing by elevating the right leg or left arm while firmly bracing the knee.

Also in the follow-through motions in the javelin throw (Figure 3) or gymnastics, the remaining energy that has not been released to the knees is transformed into potential energy by raising both arms high, thus increasing the potential energy of the entire body (center of gravity).

The same principle applies to a skier who slows down by moving up a slope: Raising potential energy reduces kinetic energy.

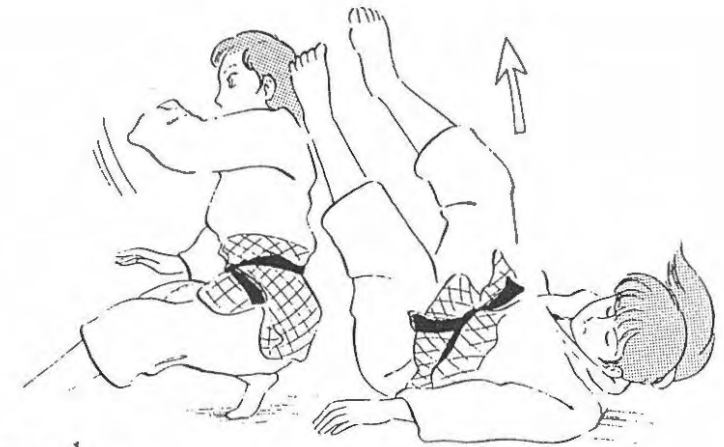


Figure 1: Defensive fall (ukemi) in judo



Figure 2: Baseball pitch follow-through

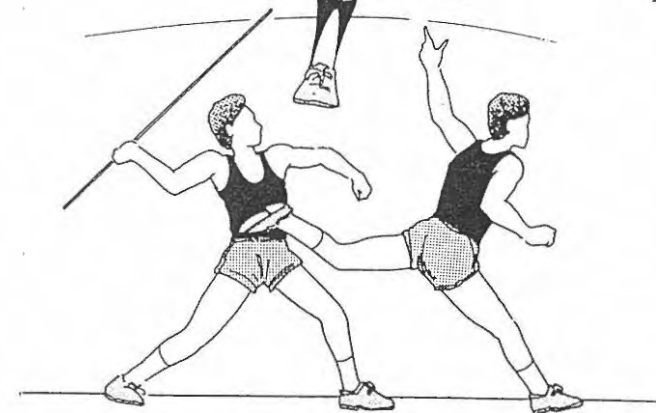


Figure 3: Javelin throw follow-through

28. A downswing from a higher position leads to a longer shot!

It is often said that you can hit the longest shot by swinging down a club from the highest position possible. Is this true? Let's see.

Since the golf ball and clubhead are both small, it is usually difficult to accurately hit the ball at the "sweet spot" (hit the ball squarely). It is therefore important to swing a club along an imaginary plane (the swing plane) so that the arms and the club always move through the same plane (Figure 1).

Yet, swing planes have different angles due to such factors as player height, club length, and personal habits, as indicated in Figure 2.

The deeper the swinging angle, the higher the position of the arms and club. Thus, a greater amount of potential energy and gravitation can be effectively utilized to accelerate the club head speed, producing a longer shot.

Generally speaking, the player whose swing plane is at a moderate angle (sometimes called a flat swing) cannot hit a long shot compared to the player with a deeper swing angle (an upright swing).

However, abruptly switching to a swing with a deeper angle is not advisable, since it will strain some parts of the body unnaturally, resulting in inaccurate shots. It is true that the top-of-the-swing should be as high as possible, but it is more important to find the most suitable swing plane for you.

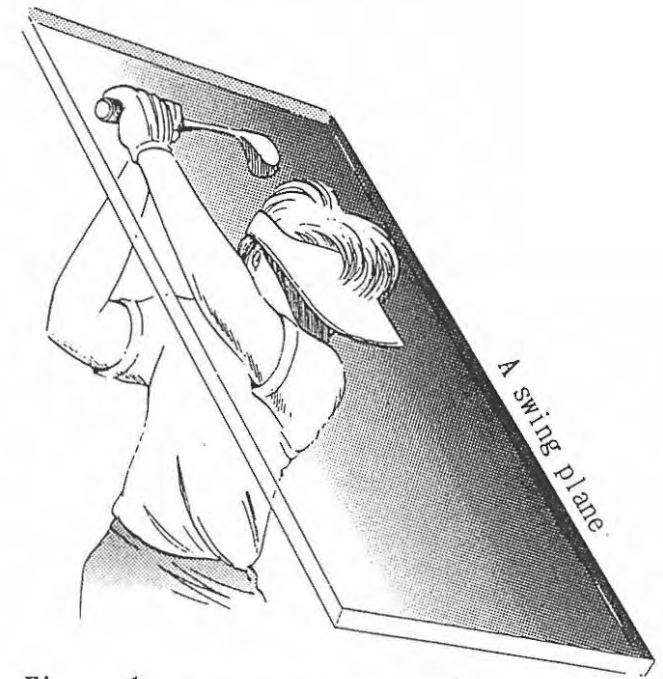


Figure 1: A swing plane in golf

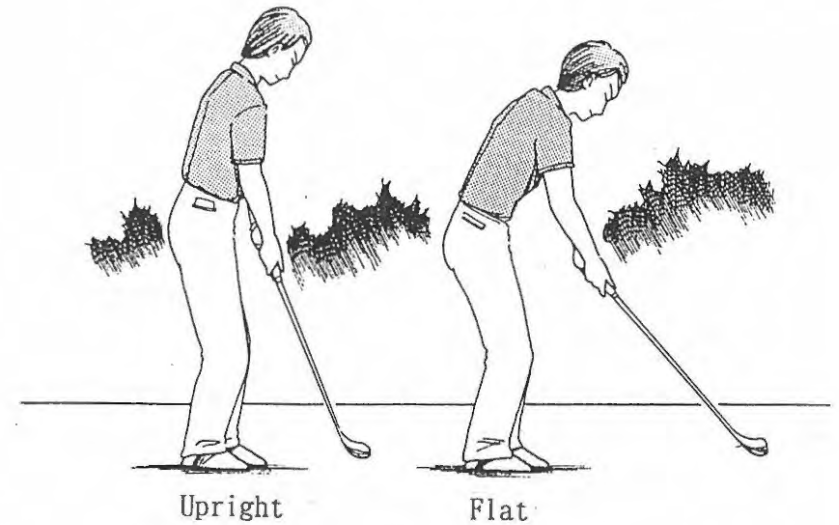


Figure 2: Only if you can swing from as high a point as possible!

29. Does a high elbow enable a faster pitch?

Modern sports are ever evolving for faster, stronger, and longer performance. Strengthening muscles through training approaches that incorporate scientific methods and achieving optimal performance through effective use of gravity are both necessary.

Next, we will examine several movements in baseball (an overhand throw, Figure 1), tennis (a service, Figure 2), javelin throw (a throwing motion, Figure 3), badminton (an overhead stroke, Figure 4), volleyball (a spike, Figure 5).

A common feature among all these motions is that they utilize a downswing motion from a high position, or raise the elbow above both shoulders immediately before throwing or hitting.

One of the reasons for this phenomenon is that to release or hit an object from a higher position, the arm has to move through a greater arc.

If the elbow is kept bent or remains in a low position, the arm is naturally unable to move in a big circle or hit an object at a high position, which means that the player cannot make effective use of gravity.

Furthermore, in order to fully utilize muscle power, particularly in bending or twisting backwards, you must keep your arm bent until maximum velocity is reached, and then hit an object by rotating your arm at the elbow, maintaining its elevated position.

Female athletes, children, and anyone who finds arm rotation relatively difficult, will benefit a great deal from consciously introducing this principle into their approaches.

<What is common in these sports movements?>

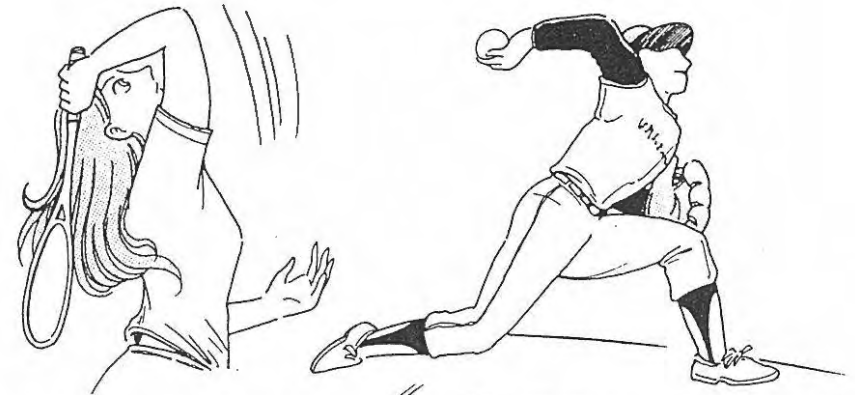


Figure 2: Tennis

Figure 1: Baseball

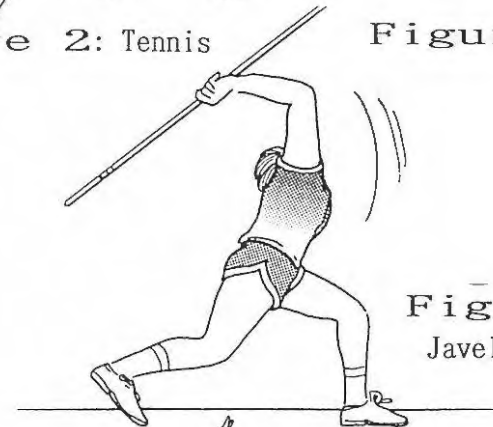


Figure 3:
Javelin throw



Figure 5: Volleyball



Figure 4: Badminton

30. Is gravity also an effect of "action-reaction"?

We have observed how various sports movements effectively utilize gravity. In this section, we will look further into this matter by considering the baseball movements indicated in Figure 1a, 1b, 1c, 1d.

- a. A ball is thrown downwards from a high position.
- b. A high windup reserves a great amount of energy for the pitch.
- c. A bat is held in an elevated position, and then swung downwards to hit the ball.
- d. A pitcher throws the ball downwards from an elevated pitcher's mound.

Each of these motions makes use of gravity. But what is "gravity" anyway?

Figure 2 shows an apple falling off a branch. Gravity is working on the apple. What is the counteracting force to this gravity?

All force works in interactive relationships between two objects, so the gravity working on the apple cannot exist alone. What then constitutes the interactive part of that force?

The answer is "universal gravitation," which causes the earth and the apple to attract each other. In other words, the gravity and the universal gravitation make a pair, creating F and $-F$, or the action and reaction.

The gravity we use for various sports movements can be more effectively utilized.

If we extend our view to include the earth or the universe, all concepts related to gravity can be explained by applications of action and reaction.

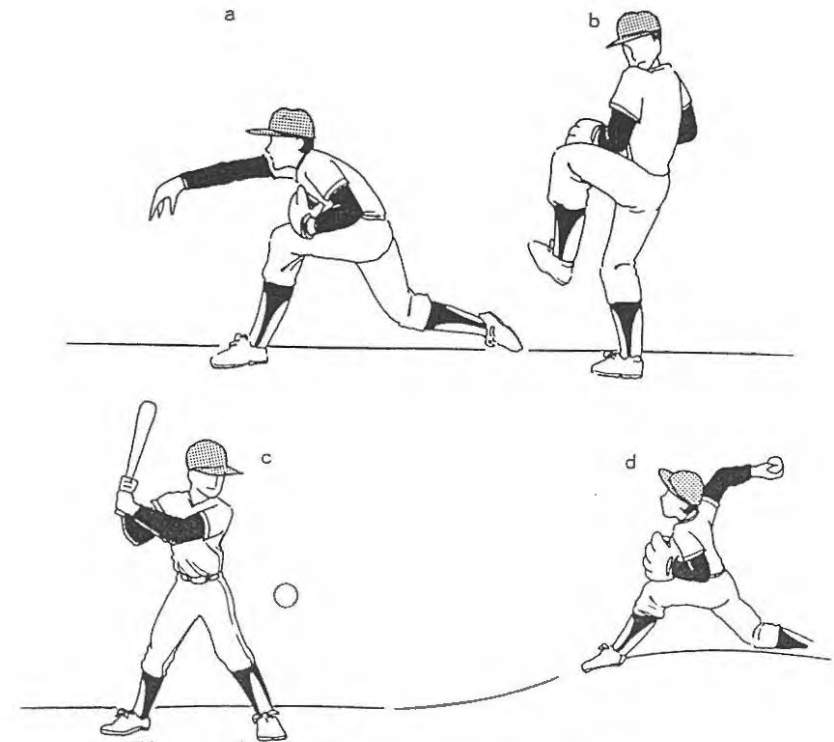


Figure 1: How does baseball use gravity?

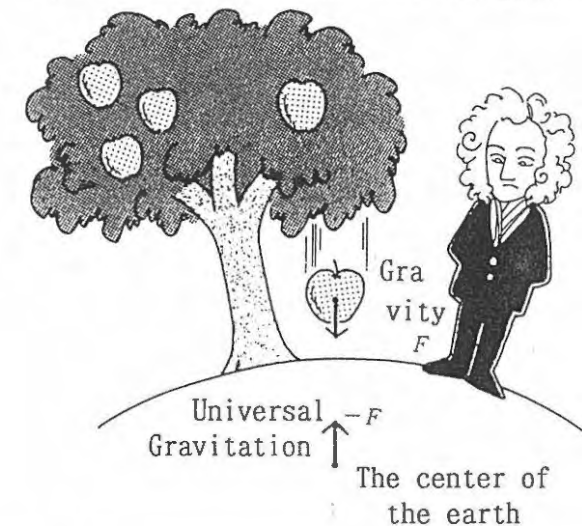


Figure 2: What is the essential nature of gravity?

31. Does weight shift utilize gravitation ?

We all wish to throw or hit a ball farther and more powerfully. To do this, we must effectively use the upper and lower parts of the body.

In the shot put event, in which a heavy shot is thrown as far as possible (Figure 1), the athlete kicks once or twice with a leg to accelerate the horizontal movement of his body, and he pushes the shot with his hand to increase its velocity. This kind of movement requires a quick weight shift.

How about golf (Figure 2)? In this case, too, a lateral motion is necessary to give the ball horizontal momentum. A closer look will also reveal that the center of gravity, first located at a higher position, dips a little immediately before impact. This dipping, which may not be very great, transforms potential energy to kinetic energy in order to drive the ball.

A swift horizontal movement increases lateral kinetic energy, which helps maximize the effects of potential energy derived from a high center of gravity.

Some people claim that there is no lateral movement in golf; however, sufficient power cannot be exerted without this weight shift. The amount of energy involved in the shift is not as great as in shot putting.

Even a jump of five centimeters on a table creates a large impact. Can we transmit that impact to a ball? Think of frequently - given advice: "Put your weight into your pitch," or "Put your weight into your swing." The validity of such advice is based on this principle.

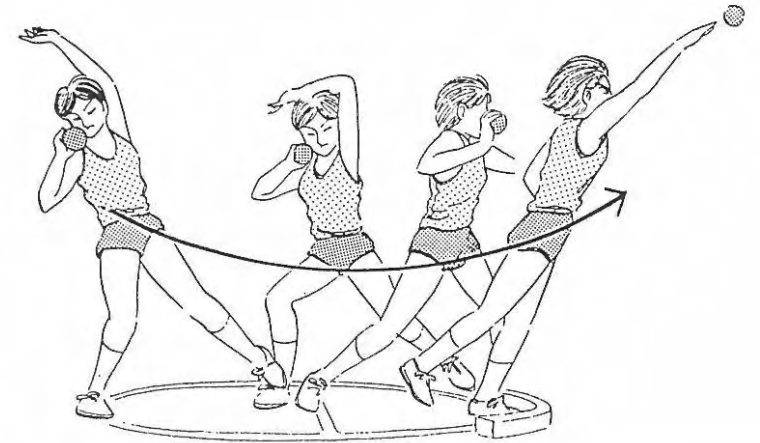


Figure 1: Shot put... Initiate the motion from a high position and dip the body; then laterally move gives the horizontal momentum.

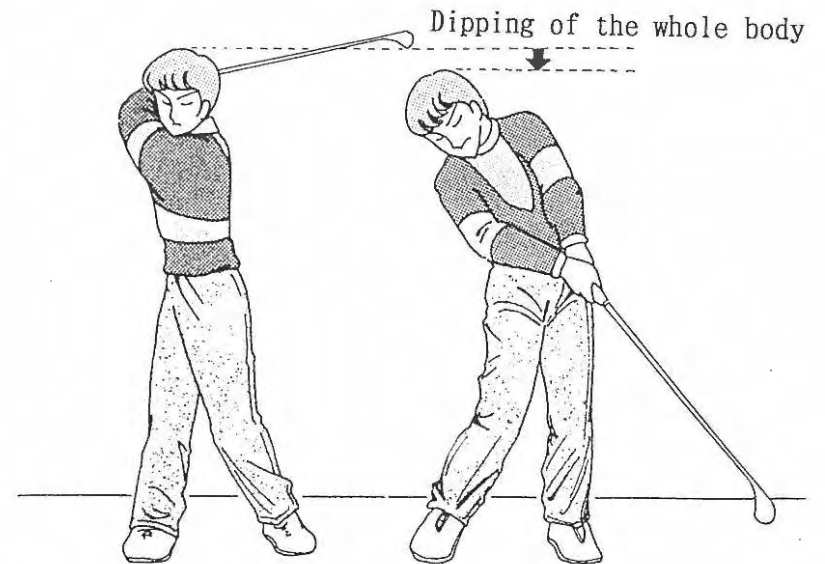


Figure 2: Weight shift in a golf swing... dipping the whole body greatly enhances the effects of the weight shift. Dipping of the whole body

Chapter 5

Sports Movements: Centrifugal Force

Quiz: How can the two balls be simultaneously put into the corners?

Q: Two small iron balls are placed inside a groove shaped like the letter W. How can we put these balls into the pockets on both ends, and can we do it simultaneously?

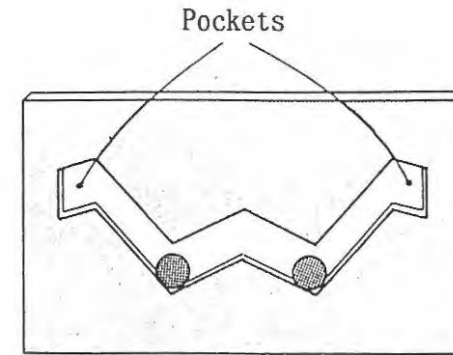
It is easy to put one ball into one pocket, but when you try to sink both balls, one always seems to fall out. What should we do?

A: The answer is to utilize centrifugal force; which will easily solve this puzzle.

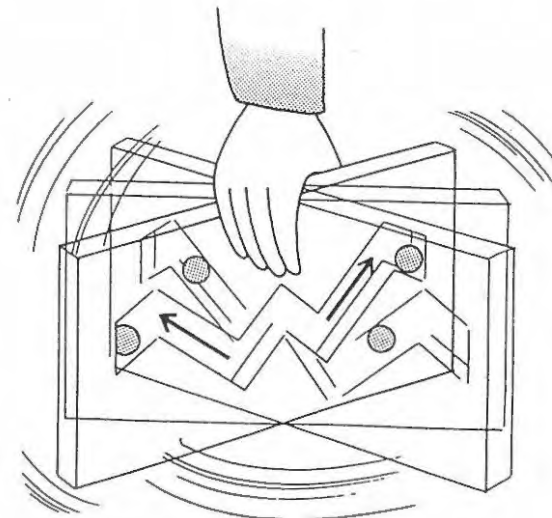
Hold the center of this board on your fingers and rotate it several times. The two iron balls, using the momentum of horizontal rotation, will move upwards and toward the outside and enter the pockets neatly.

An object tends to go down a downhill slope due to gravity, but when centrifugal force is greater than gravity, it will move up the slope. In this way, centrifugal force works on every rotating object. We may feel it substantially when swinging a bat or moving along a curve.

In this chapter, we will look into how centrifugal force affects sports movements.



Q: How can we put them into the pockets simultaneously?



A: Rotate the board and utilize centrifugal force.

32. Skiing and a roller coaster work the same way on curves!

When you ride on a roller coaster, you may notice that at curves, the rails are inclined inward and the roller coaster itself leans toward the inside (Picture 1, Figure 1a).

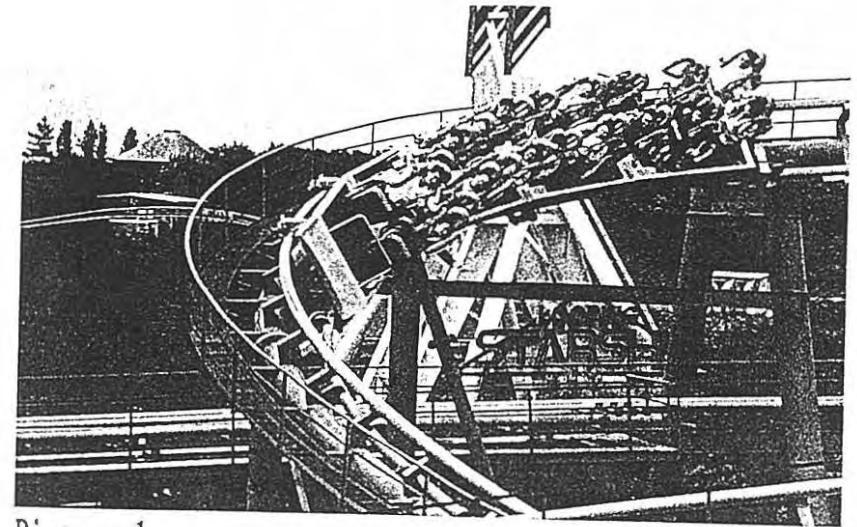
At this moment, centrifugal force is pushing toward the outside of the curve. Gravity and centrifugal force on the rider constitute the resultant force, which works perpendicular to the rails. So, the rider positioned perpendicular to them can pass the curve comfortably without falling.

But when the roller coaster runs at a reduced velocity on the same curve (Figure 1b), the centrifugal force is also diminished. So is the inclination of the resultant force on the rails. In an actual roller coaster, the horizontal centrifugal force is not so great; it is, at most, about twice a rider's body weight.

The same principle is used for turning in skiing (Figure 2). The faster you turn on a curve, the greater the centrifugal force required; and the more you must incline your body. If the degree of inclination exceeds a certain level, edging may not work, and you may not be able to hold the snow with your ski edges. Thus, you will fall.

If you judge a curve to be too steep to turn, you must slow down before the curve, thus reducing centrifugal force and enabling a smooth turn. The same is true for runners in track event and race cars when they round the curves of the racetrack.

These observations confirm that it is very difficult to accelerate on a curve.



Picture 1: A curve on an amusement park roller coaster (Yomiuri Land, Tokyo)

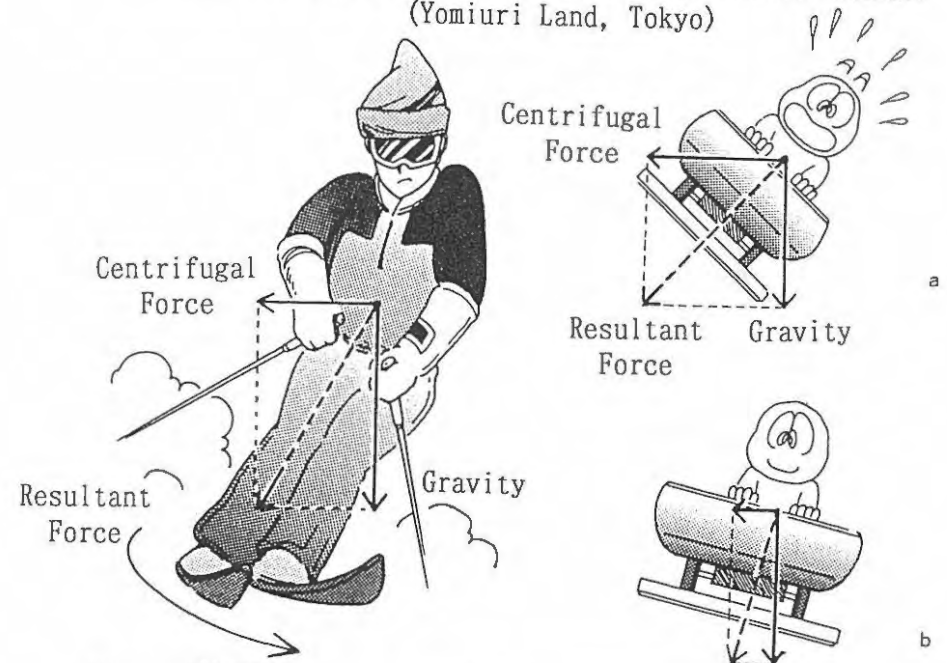


Figure 2: What kind of force is working when executing a skiing turn?

Figure 1: What kind of force is working at a curve of the roller coaster?

33. Great effects of centrifugal force!

We have observed that all rotating objects are affected by centrifugal force pushing outwards. How much does this centrifugal force affect actual sports movement?

First look at Figure 1, which shows a hammer throw. Notice the strong centrifugal force working on the upper body in an outward direction, which is balanced by leaning the body in the opposite direction and firmly bracing the foot against the ground.

How much force is actually working at such a moment? Let's check it out with the three examples: Figures 1, 2, and 3.

The amounts of centrifugal force at work may vary from person to person, but even the swing of an ordinary person can involve, on average, almost half of these levels, which far exceeds expectations and may produce lower back injury.

From these figures, it is clear that delivering an object to a distant place requires great rotation velocity and a strong grip or use of muscle power to check the centrifugal force derived from it.

Particularly in the hammer throw, a tremendous amount of centrifugal force is created. It is equivalent to holding a 220 kilogram weight, which is unsustainable with only leaning the body. But the entire body is also rotating with the hammer, creating centrifugal force in the direction opposite to the hammer and thus balancing it out the effective weight.

Similar movements can be observed to a lesser extent in baseball or golf. When we swing a bat or club, the body slightly rotates. We will investigate this in the next chapter as it relates to movements in the center-of-mass system.

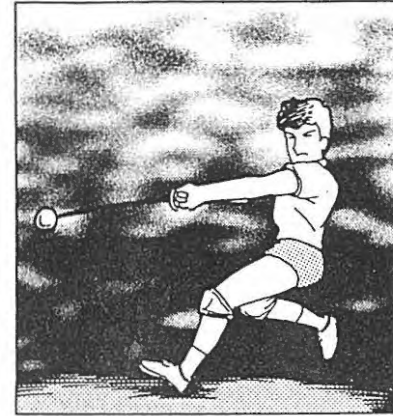


Figure 1: A hammer throw:
a hammer's weight = 7.3 kg
⇒ distance = 80 m

Weight of a hammer: 7.3 kg
Maximum rotation velocity: 27 m/s
Length of an arm: approx. 2.5 m
Centrifugal force = 220 kgw
(about 30 times greater than
the weight of the hammer)

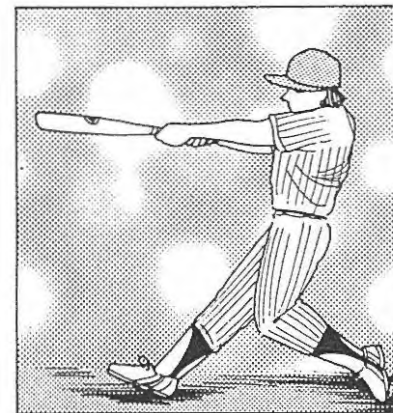


Figure 2: Batting in baseball:
a ball's weight = 150 g
⇒ distance = 120 m

Weight of a bat: approx. 1.0 kg
Swing velocity: 35 m/s
Length of an arm: approx. 1.3 m
Centrifugal force = 100 kgw
(about 100 times greater than
the weight of the bat)

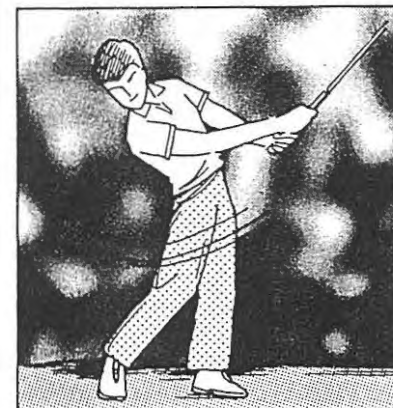


Figure 3: A golf drive:
a ball's weight = 45 g
⇒ distance = 270 m

Weight of a club: approx. 0.35 kg
Clubhead velocity: 55 m/s
Length of an arm: approx. 1.8 m
Centrifugal force = 60 kgw
(about 170 times greater than
the weight of the club)

34. Do swinging arms help you run faster?

Can you run comfortably with both hands in your pockets? Of course not! This kind of running is not only dangerous when you stumble, but also makes running unnatural and difficult. If your arms are allowed to swing in large arcs, you can run much more easily. Short-distance running coaches often advise, "Swing your arms in large arcs." (Figure 1).

As shown in Figure 2, a "freely-swinging" light stick with a weight on the tip is hung under a fulcrum on a ceiling. If this weight is released from the horizontal position, maximum velocity will be attained at the lowest point, and centrifugal force will work on it. The centrifugal force at this moment is, according to detailed calculations, more than twice as much as gravity. The sum of gravity and centrifugal force amounts to three times as much as the original weight. In other words, when swinging the fulcrum supports three times more weight than it does in the stationary state. Of course, if you increase the speed of the swing, more force is created.

The same phenomenon applies to arm swinging. An adult male's arm weighs about three kilograms; both arms together weigh almost six kilograms. When you run while swinging your arms through large arcs, centrifugal force works in the downward direction, which has the effect of lowering the whole body through the shoulders. This makes pushing off the ground with your legs more powerful.

In jumping or running, we basically move our body by utilizing the reaction to pushing off the ground. Swinging the arms, therefore, reinforces our movements.

In jumping, the reaction from raising the thigh of the other leg is also utilized to increase the pushing force on the ground (Figure 3).

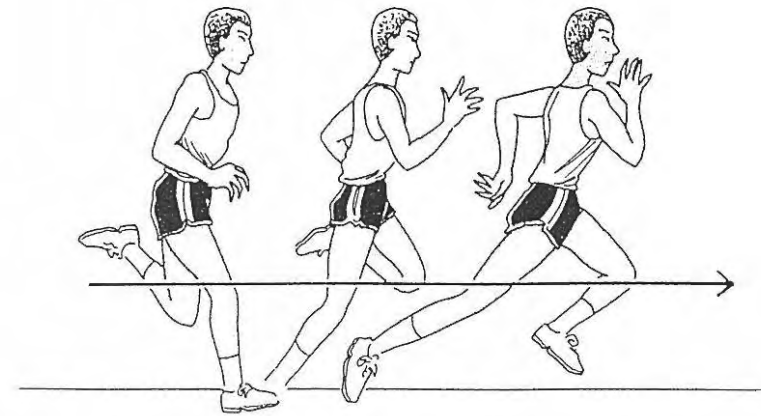


Figure 1: A short distance run (Arm swinging helps you run faster)

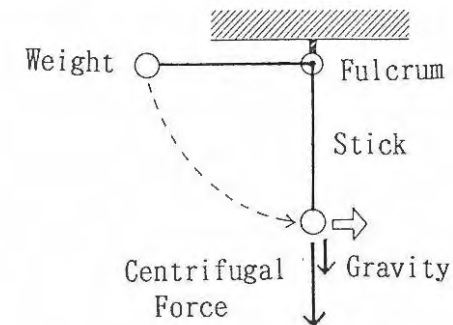


Figure 2: At the lowest point of the pendulum swing, weight increases as much as three-fold.

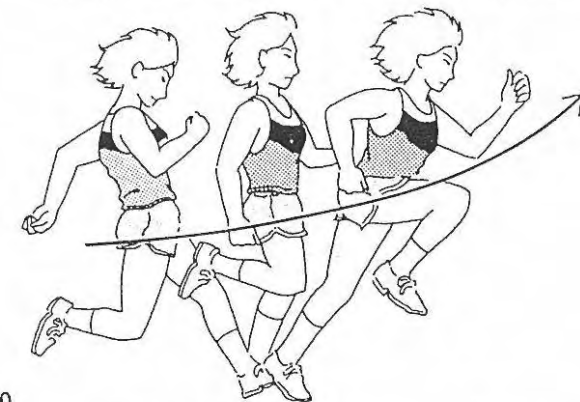


Figure 3: The take-off in a long jump (Kicking force on the ground is increased by arm swinging and forcefully raising the thigh.)

35. Why jump with both arms swinging ?

In Figure 2 on the previous page, suppose the weight is dropped and swung from the highest point over the fulcrum (above the ceiling). At the lowest point of the swing, its centrifugal force is maximized. According to detailed calculations, it is as much as four times than the force of gravity. The sum of centrifugal force and gravity is five times the weight supported by the fulcrum.

To cast off and fully circle the horizontal bar in gymnastics, similar forces are working. Naturally, the bar itself must be strong enough to sustain such weights (Figure 1).

We have observed that centrifugal force is created by swinging the arm around the shoulder, which can be utilized by a wide variety of sports movements besides running.

Particularly in jumping events, both arms are pulled back and swung forward in sweeping rotary motions. When both arms are involved, greater centrifugal force will be obtained, which is then utilized to enhance the kicking force to jump higher.

In volleyball, when jumping to spike or block, both arms are swung to enhance the jumping force of the legs.

Also, as in Figure 2, similar motions are used to jump over obstacles. In this case, however, after both arms swing in big arcs once, they then swing upward for a second time. This second motion is intended to lift the body higher, using a principle not yet discussed.

When both arms swing up, the reaction lowers the body; after the arms are fully extend upward, momentum lifts body. In this way, you will move further upward.

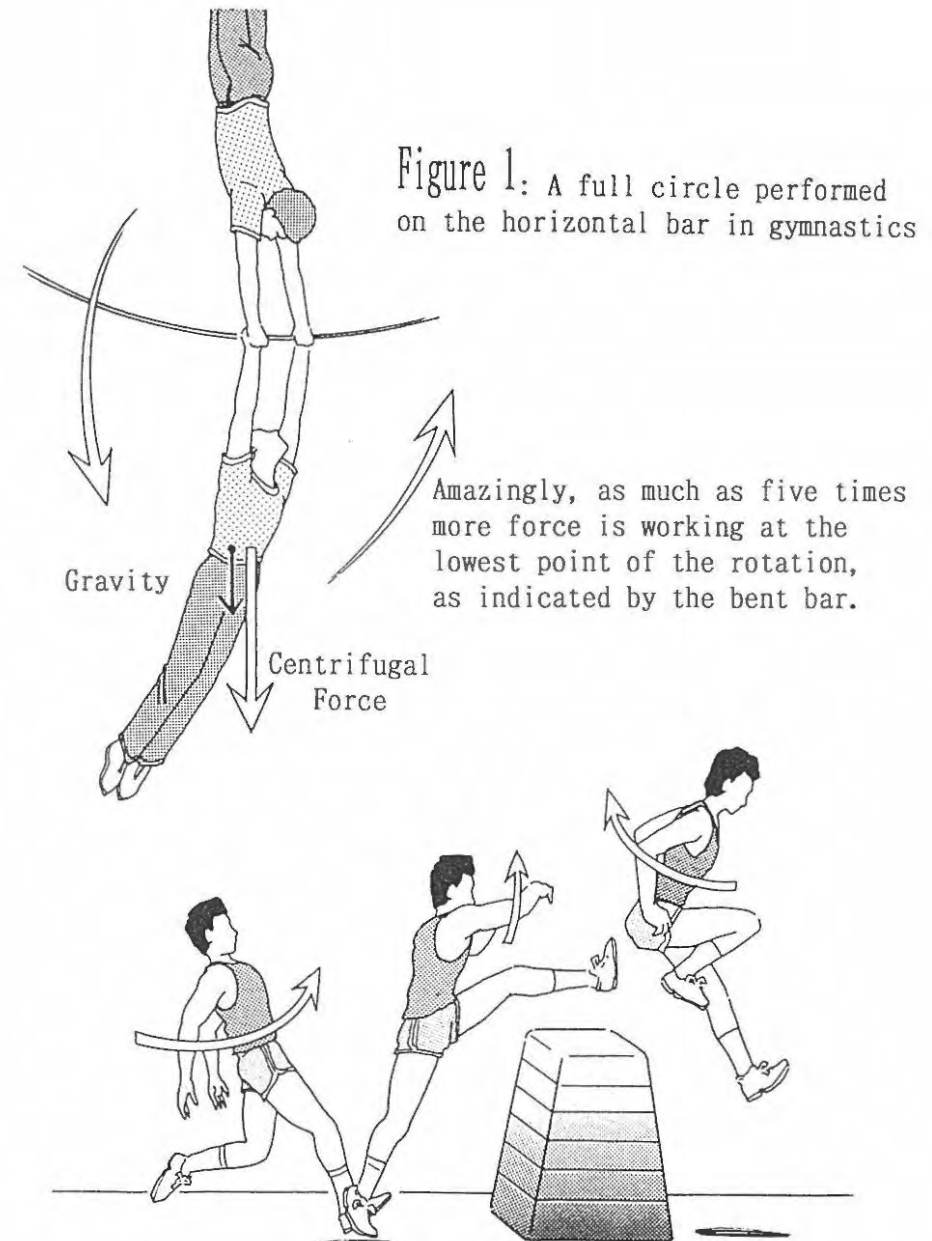


Figure 2: Jumping over an obstacle (swinging both arms and jumping up; and then trying to maintain the altitude by swinging the arms downward).

36. Does centrifugal force work upward ?

Figure 1 indicates an underhand softball throw. Swinging the arm in an arc creates downward centrifugal force, which works to press down the body, thereby requiring firmly braced legs. This combination stabilizes the whole body enough to throw a powerful pitch.

On the other hand, in the case of an overhand throw (Figure 2), the arm is swung in the direction opposite to an underhand throw. The upward centrifugal force slightly lifts the body. As a result, after the pitch the body's center of gravity moves slightly upward.

In the case of a tennis serve (Figure 2, 97), the ball is hit overhead. Top-ranking male professional players can hit a ball at more than an estimated 200 kilometers per hour. At that moment, the arm's rotation velocity must be tremendous.

Actual serves are delivered along with leg kicking and jumping. Furthermore, the arm and racket rotation creates an upward centrifugal force, which effectively lifts the body.

In the "tomoe" throw, a throwing technique in judo (Figure 3), the thrown person rotates around the person throwing. Upward rotation again creates an upward centrifugal force. The throwing person can thus comfortably throw over his opponent, because the force of the opponent's weight is effectively reduced by the upward force.

Quick motions accompanied by upward rotations are, in general, strongly affected by upward centrifugal force, which has the effect of lifting the body. Please look further into this effect for yourself.

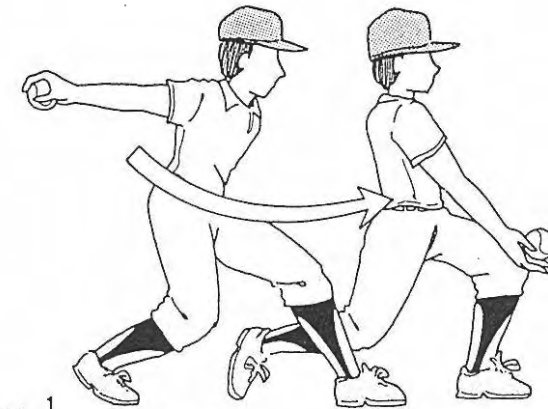


Figure 1: An underhand throw in softball

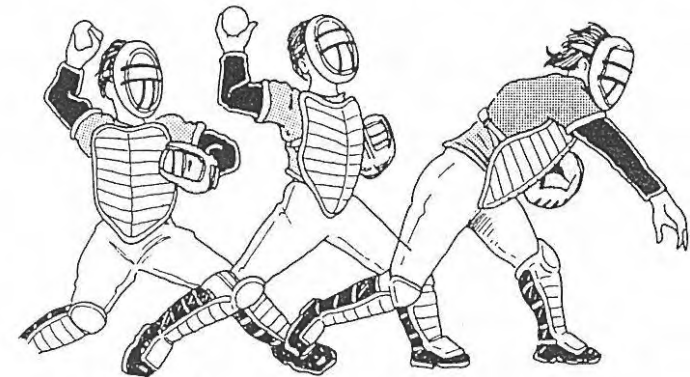


Figure 2: An overhand throw in baseball



Figure 3: A "tomoe" throw in judo

37. Does centrifugal force pull out your arm ?

Did you ever hurl a stone with all your might when you were a child? Did you feel pain in your arm joint? This can be explained by centrifugal force.

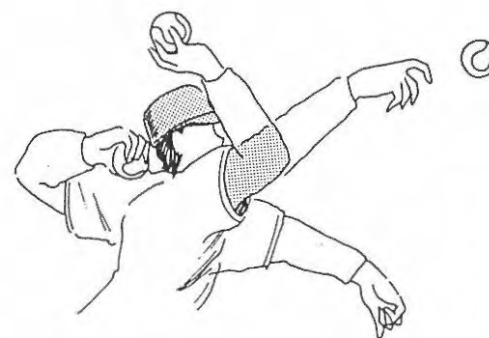
The centrifugal force on a baseball (Figure 1) or on a racket swung in a tennis serve (Figure 2) can be estimated to be equivalent to holding a weight as heavy as 30 kilograms. The arm has to sustain this weight.

This is only the amount of the centrifugal force working on the ball or the racket, and does not include the centrifugal force working on the arm. The centrifugal force is the force directed outwards; particularly in the case of a tennis serve, the racket may fly out of your hand if your grip is not firm enough to overpower the centrifugal force.

To overcome this force, we need the force to attract inward: "centripetal force". In other words, the racket is held in hand because these two forces balance each other.

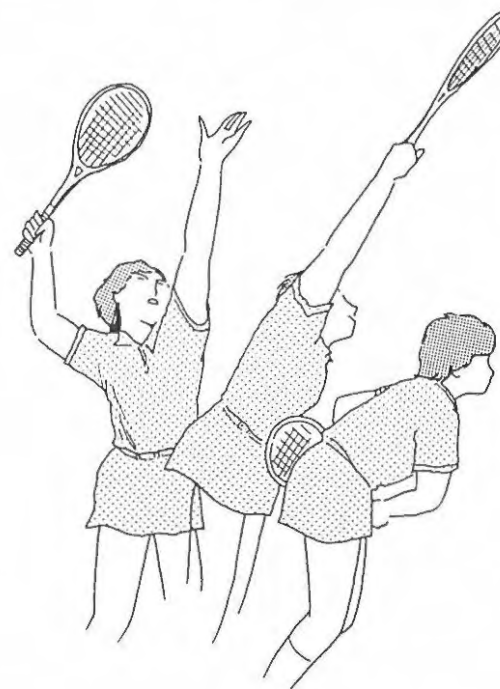
If a ball is hit on the "sweet spot" of a racket, the centrifugal force is adequately reduced and load on the arm is alleviated. But if the racket does not hit the ball squarely or if it misses the ball, a substantial force must be absorbed by the arm; if the load is excessive, it will cause injury.

The same thing is true in baseball. If the force of the swing is adequately transferred to the ball, the load on the arm will be alleviated. In the case of throwing a stone, because the stone is too small for the force to be transferred properly, a substantial portion of the centrifugal force is loaded on the arm, straining the arm joints.



Weight of the ball: 0.15 kg
Velocity of the ball: 40 m/s (= 144 km/h)
Turning radius: 0.7 m
Centrifugal force = 35 kgw (about 230 times greater than the weight of the ball)

Figure 1: How much centrifugal force is working on the ball immediately before the pitcher hurls it?



Weight of the racket: approx. 0.35 kg
Rotation velocity of the racket 30 m/s
Length of an arm: 1.1 m
Centrifugal force = 30 kgw (about 86 times greater than the weight of the racket)

Figure 2: How much centrifugal force is working on the racket immediately before impact in a tennis serve?

Chapter 6

Sports Movements: Center of Gravity

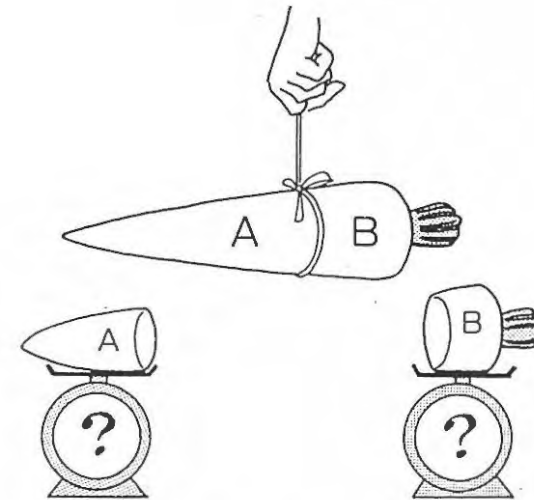
Quiz: Which of the two pieces of a carrot is the heavier?

Q: Suppose we hang a carrot with a string as in the Figure and keep it horizontally balanced. Next, imagine that the carrot is cut into two pieces along the string, and that the two parts are weighed. Do both have the same weight? Or is one of them heavier than the other? When the whole carrot is hanging in balance, the center of gravity exists on the imaginary cutting surface along the string. Even if we rotate it horizontally in this state, it maintains its horizontally balanced state.

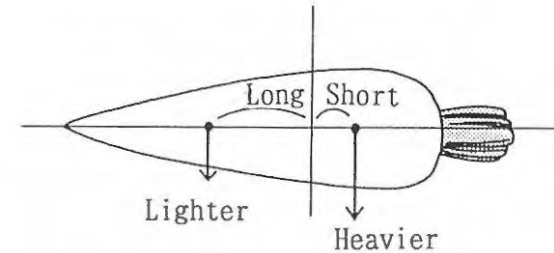
A: The answer is that B is heavier. This is the same as balancing a seesaw: a heavier person sits nearer to the fulcrum and a lighter person sits farther from it. In the case of this carrot, the whole carrot keeps its balance because the weights of separate pieces concentrate on their respective centers of gravity, thus balancing one another.

This example highlights the fact that the body's center of gravity isn't necessarily in the center of the body. We should be aware that when we extend and bend our arms or swing a bat, our center of gravity shifts constantly and is not actually in the center of our body.

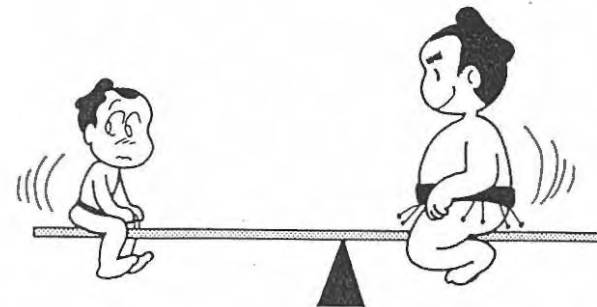
Actual sports movements will not be optimized if one follows the claim that if the lower body is strong and firm, the center of gravity will not move. In this chapter, we will think about what happens to the center of gravity in sports movements.



Q: Which is heavier, A or B (the two pieces of a carrot cut in half)



A: B is heavier than A.



Balancing a carrot can be explained by the same principle used for balancing a seesaw.

38. Is the golf tip "Don't move your head" appropriate?

I am a so-called golf maniac, hell-bent on improving my score, buried under a pile of golf magazines and instruction books. But I cannot quite convince myself of the truth of some of the comments I read in these books.

The advice, "Don't move your head when swinging," is one of these perplexing suggestions.

Figure 1 shows a driver shot performed by the world-famous Spanish golfer, Severiano Ballesteros. By looking at the stop-motion pictures of this movement, one can see how much his head moves laterally (Figure 2).

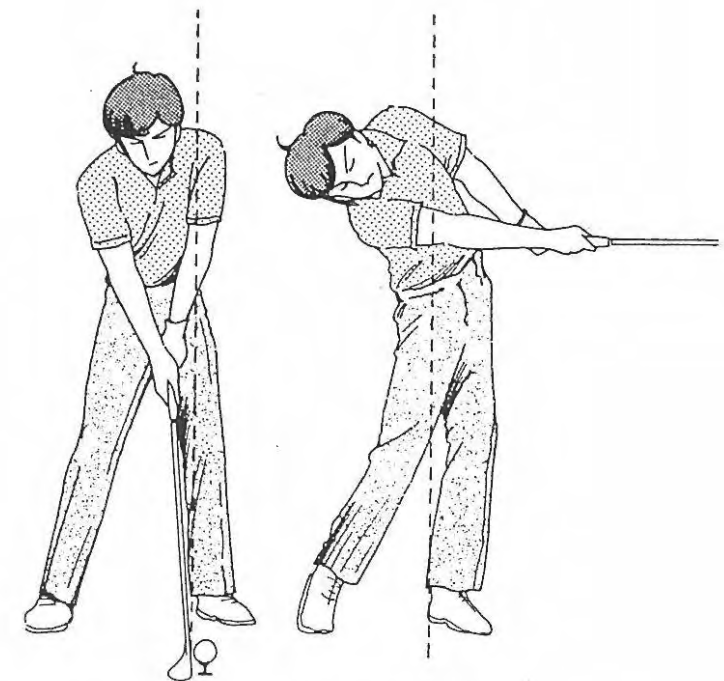
I found out that his head moves from the starting point to the right-most position by as much as 22 centimeters. Moreover, what is symbolically significant is that the head moves in the direction opposite to the ball during the swing immediately before and after impact.

I used to practice by following the gold rule, "Don't move your head," faithfully, but somehow I could not move my body in a natural manner or improve my performance. Then I decided to let my head move naturally; and my performance improved rapidly.

This idea of "Don't move your head," is widespread among amateur golfers, and is treated by them as one of the inviolable rules of golf.

However, an analysis of head movement from a dynamics' point of view has revealed that all golfers' heads move naturally to follow the movement of the body.

In this chapter, we will look at why this happens from various perspectives.



Set-up

Follow-through

Figure 1: A drive by Severiano Ballesteros

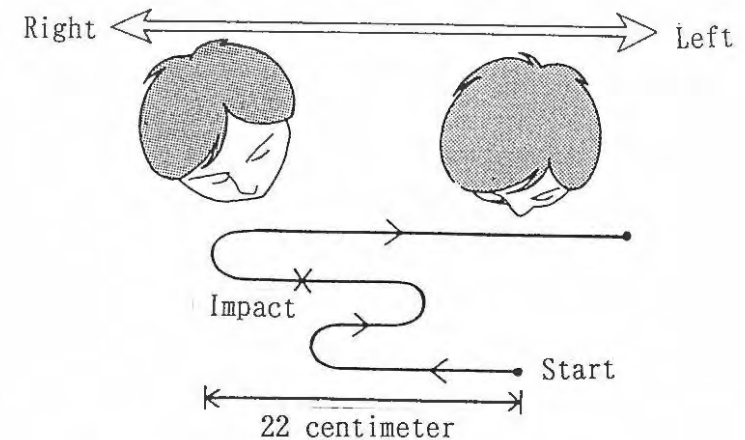


Figure 2: Pattern of the head's movement
(swaying to the right and left)

39. How does gravity relate to "action-reaction"?

In this section, we will once again look into the center of gravity of an object that is affected by action and reaction.

Suppose a person walks on a board that weighs the same as the person and that the board is resting on ice, as in Figure 1, and assume that there is no friction between the board and the ice. The force working horizontally is strictly the result of the interaction between the person and the board, i.e., the action and reaction components associated with the person's pushing off from the board and stepping forward.

When the person walks from the left end of the board to the right end, the center of gravity ("G" in the Figure 1), when observed from the outside, amazingly remains at the same place.

Figure 2 indicates a situation where two objects, one weighing two times more than the other, are repelled by springs. These two objects are accelerated by the force created by the action and reaction, and gain velocities at a ratio of 1 to 2, which remain constant over time unless affected by an outside force. The distances the two objects attain as a result are also expressed as a ratio of 1 to 2, and the location of the center of gravity remains constant.

In this way, the location of the center of gravity does not move after two objects have moved due to action and reaction. This kind of movement in which the center of gravity does not move is called a "movement in the center-of-gravity system" or a "movement in the center-of-mass system".

The above arguments have been used to explain linear motions; but as in Figure 3, the center of gravity does not move either in the case of rotary motions, which will be examined in detail later. At any event, the key to solving many problems lies in the fact that the center of gravity remains constant.

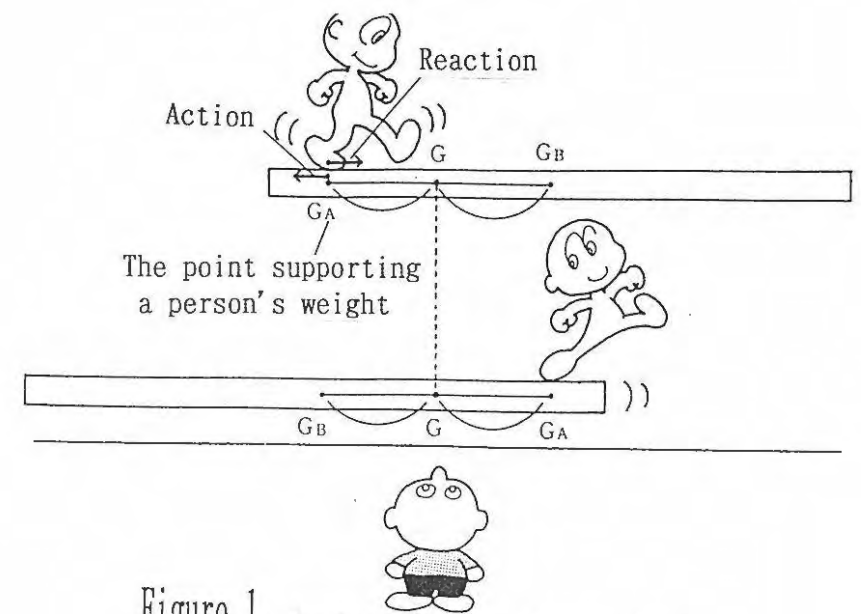


Figure 1: Action and reaction on ice
(The center of gravity does not move.)

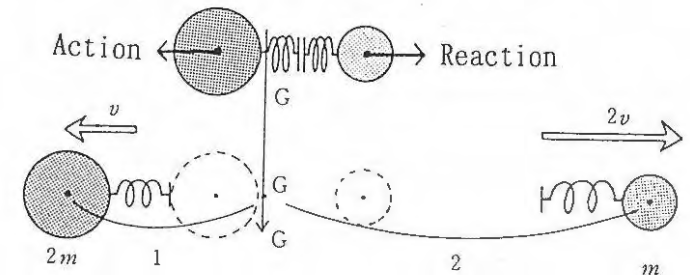


Figure 2: Separation Phenomenon (The center of gravity remains at the same place.)

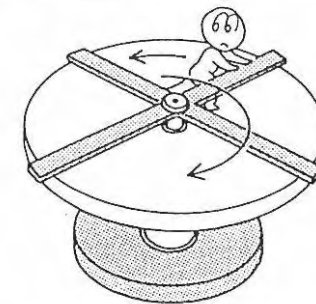


Figure 3: Center of gravity in a rotary motion
(The center of gravity remains constant since the person's weight is negligible.)