Dynamics for Improving Sports Performance

Illustrated Principles of Sports Movements

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First Japanese edition 1996
Published by Taiga Publishing Co. Ltd.
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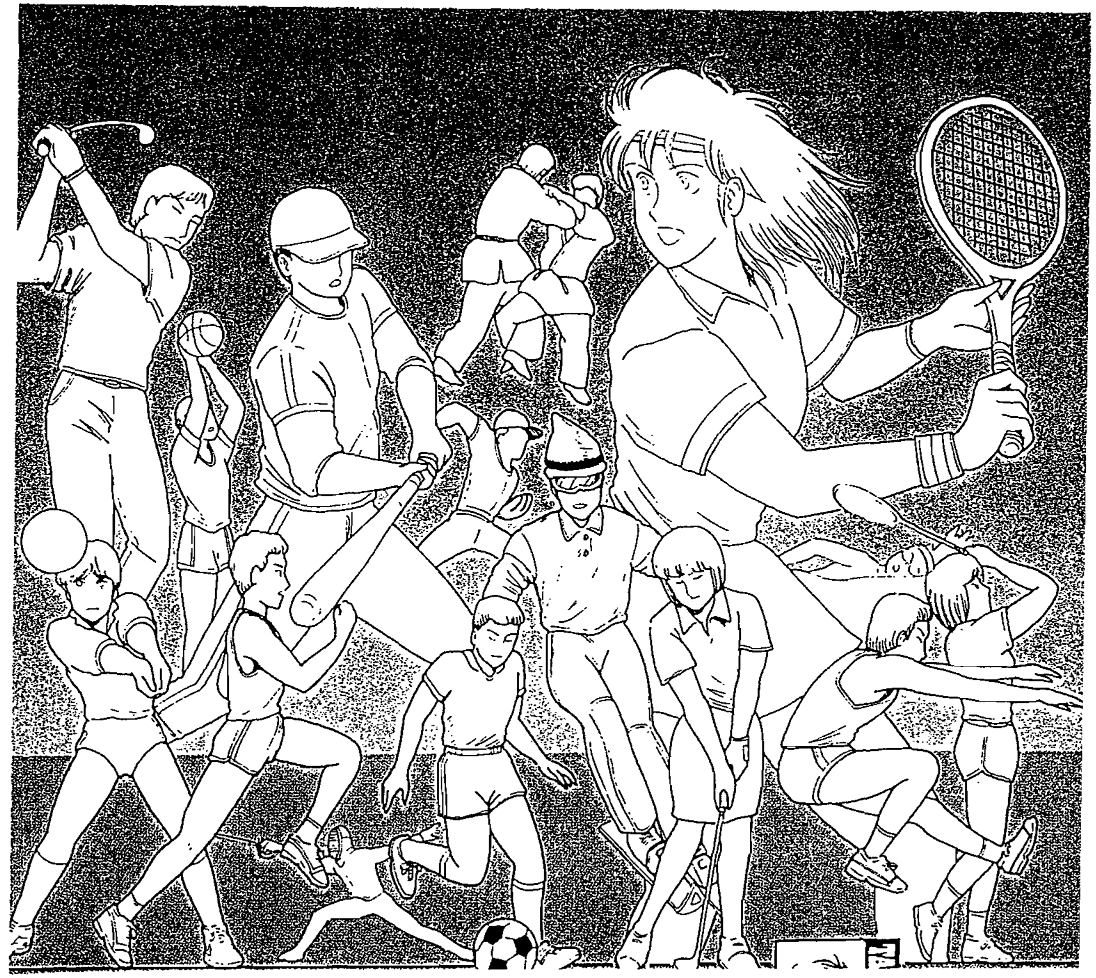

Introduction

"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 tha 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 practic circle for physical education.

December 1995

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Cover and Page Illustrations by Hitoshi Utsunomiya
Cover Design and Page Layout by Isao Owada

Prologue

What do these sports movements have in common?

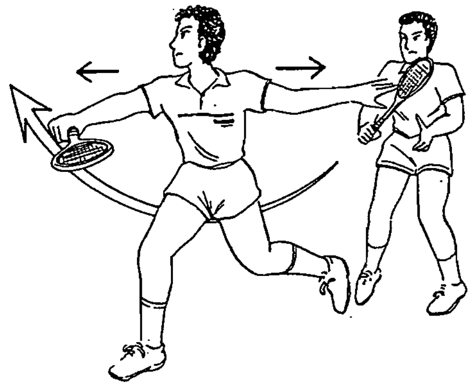
A backhand volley in tennis, a heading in soccer, and a place kick in rugby: what do these sports movements have in common? All of them involve hitting a ball to the best possible destination.

Now, if you look closely at these movements, you will realiz 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.)

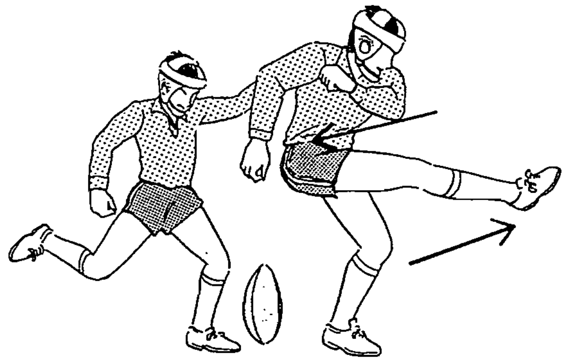
Take baseball as another example. When you swing a bat, your head and body move slightly backward. Since the head and body are heavy, even small movements can have substantial effects.

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."

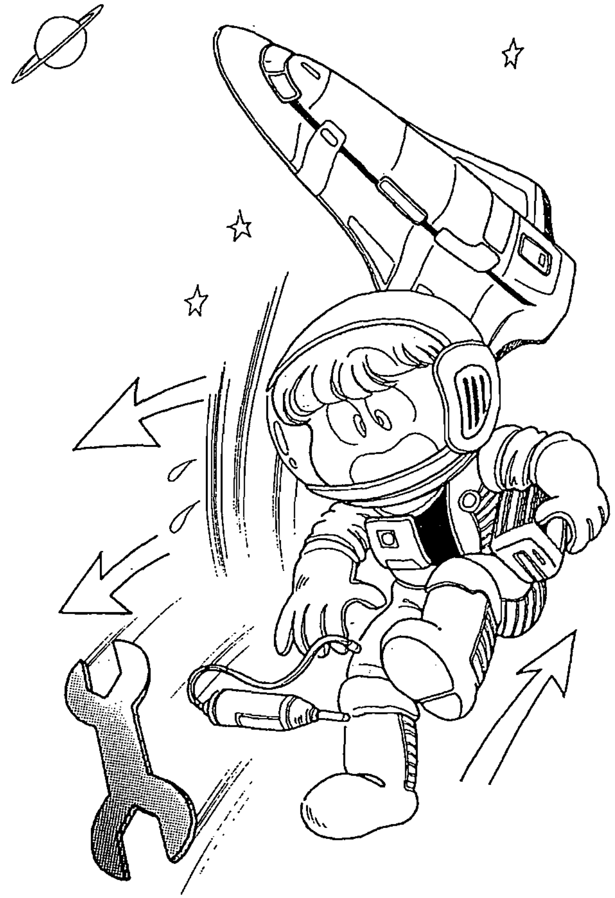
To make matters worse, he has left behind his gas-propelled gadget for a space walking and his lifeline. If he doesn't act fast, he will drift in space forever.... What should this astronaut do to get back to the shuttle?

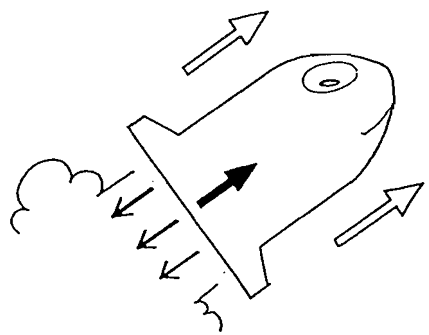
A: He should throw his repair tools in the direction away from the space shuttle. Luckily, he has many tools with him. If he throws them away from the shuttle, he can move toward the shuttle by the reactive force generated.

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.

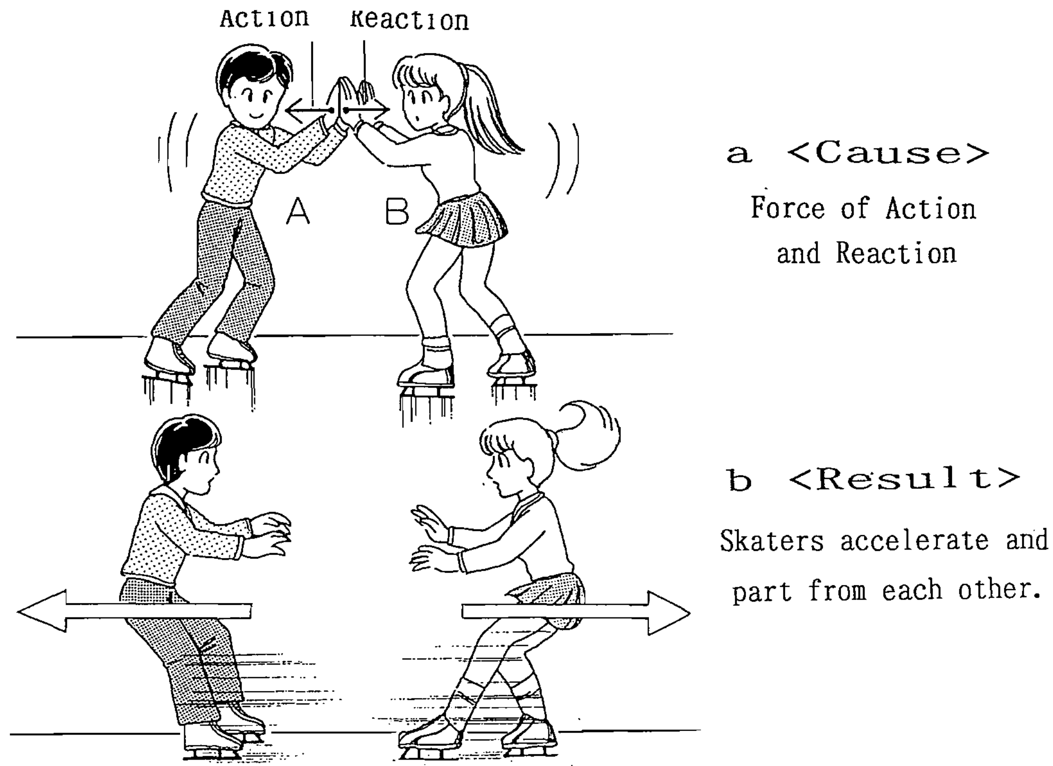


Figure 1: The result of parting from each other has a cause.

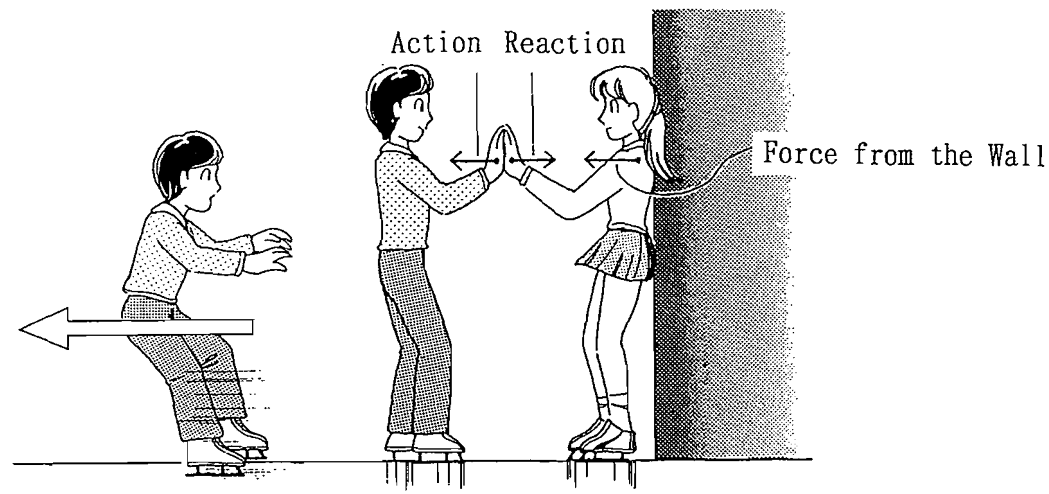


Figure 2: Sometimes the relation of action and reaction does not start a movement....

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".

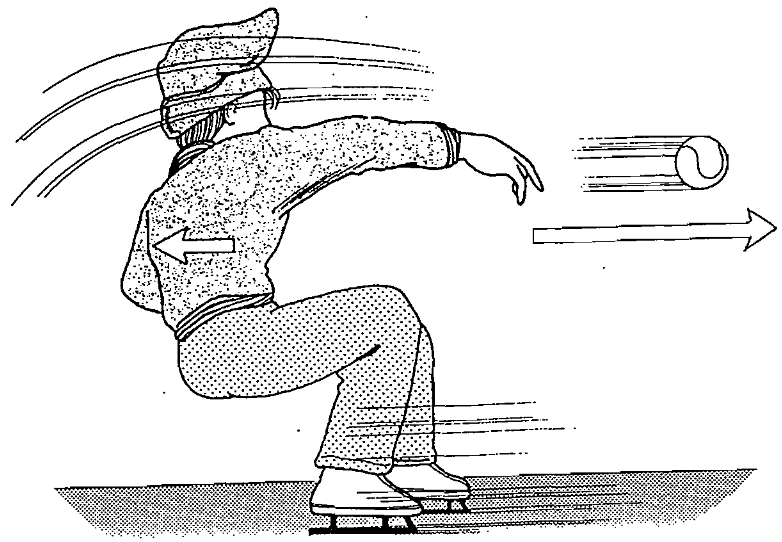


Figure 1: If a skater throws a ball, the reactive force moves him backward.

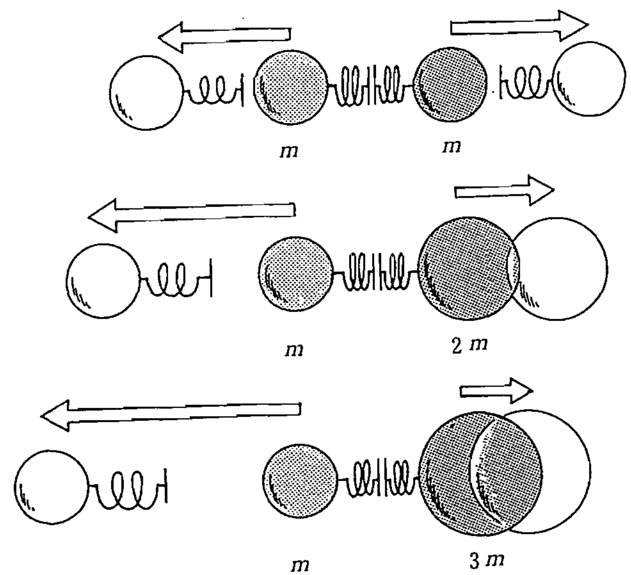


Figure 2: Which gets more power in the repulsion of two objects that have different amounts of mass?

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.

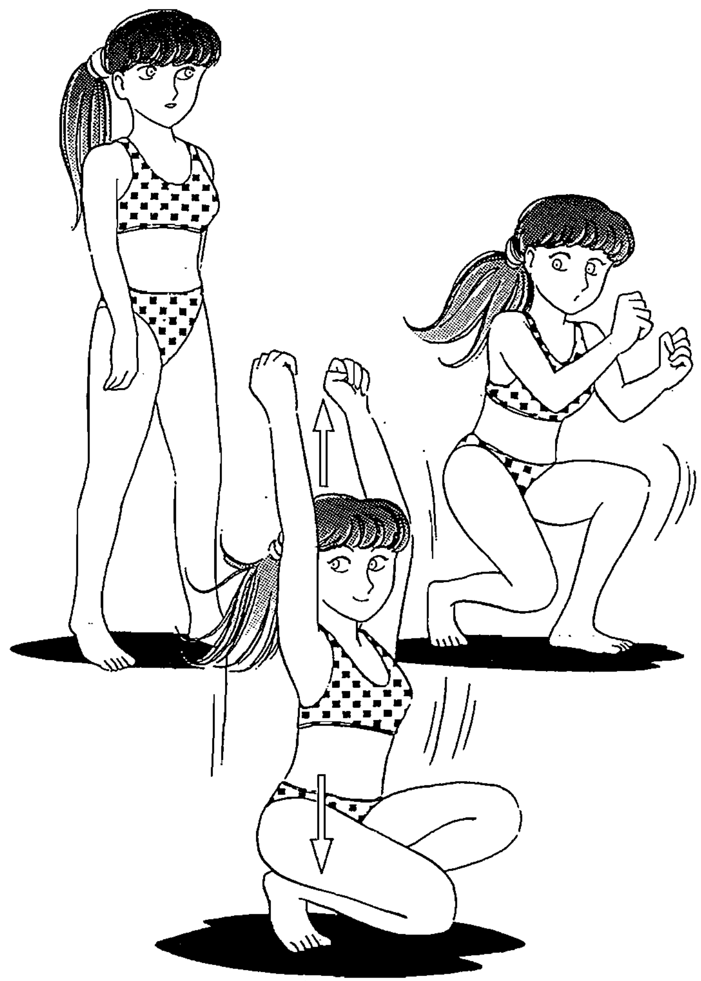
This squatting motion basically uses muscular power and gravitational pull to lower the body; still, the fact remains that part of the body is used to create reactive force for a faster and stronger movement.

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 i 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.

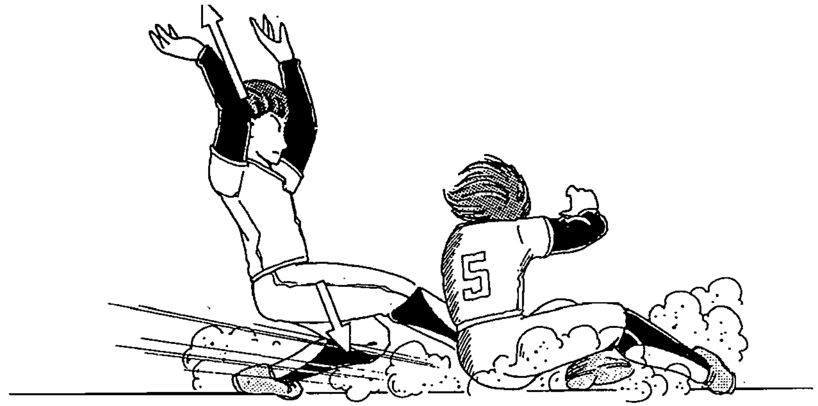


Figure 1: Sliding into base (Safely reaching a base with the arms thrown upward)

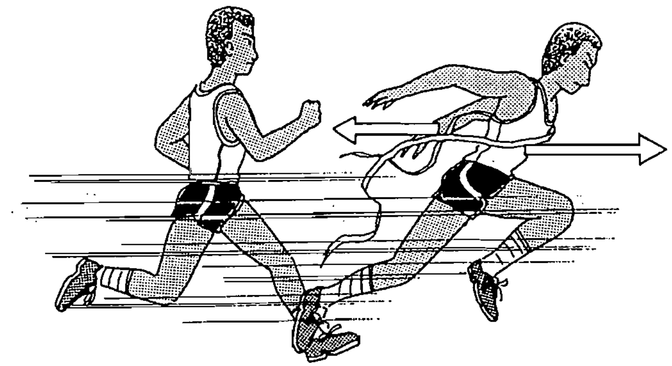


Figure 2: Finishing in a race(Winning by the margin of a torso)

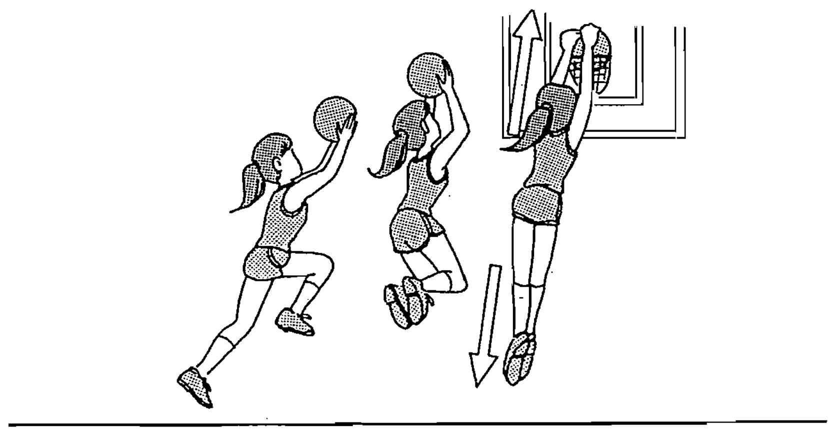


Figure 3: Dunking in basketball (A fabulous dunk shot facilitated by kicking down the legs)

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.

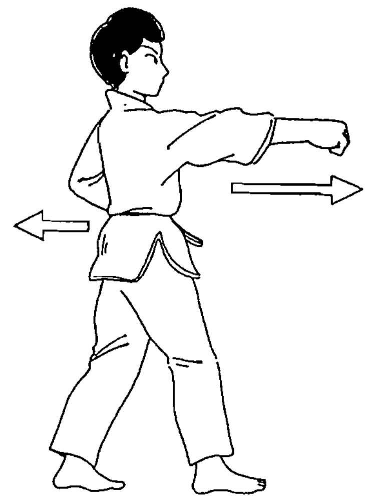
★ A tennis serve (Figure 3)

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.)



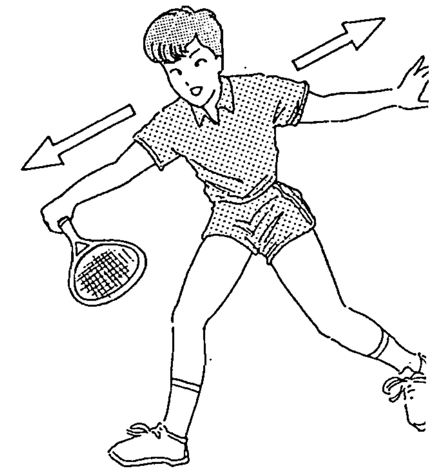


Figure 2: A backhand volley in tennis (Swinging back the other arm enables a terrific volley.)

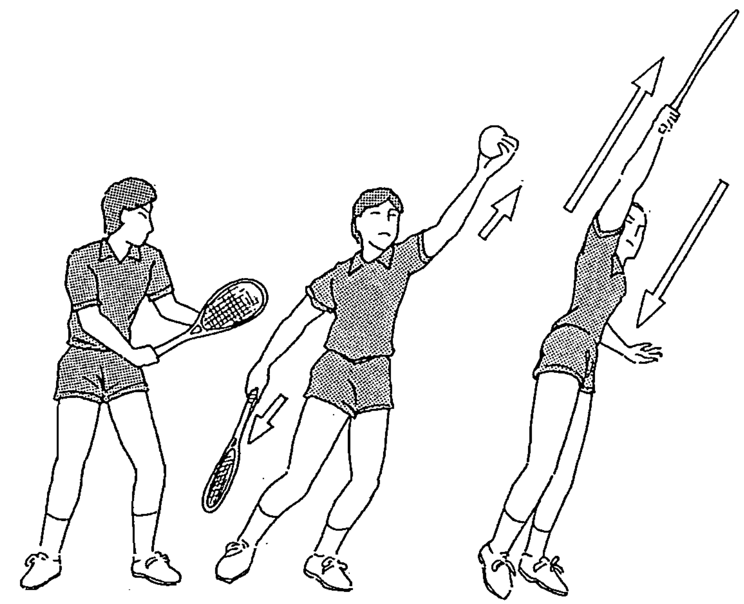


Figure 3: A tennis serve (The ball can be hit more powerfully with complementary movements.)

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.

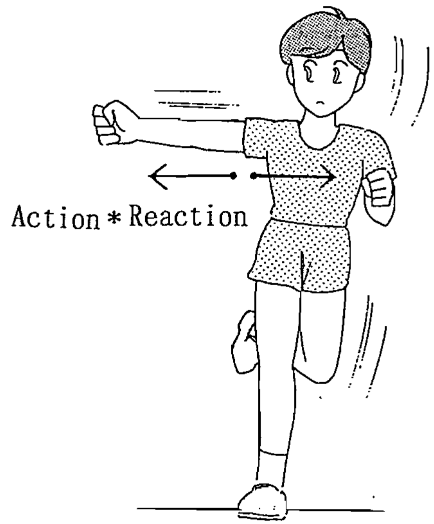


Figure 1: What if you thrust a single arm? (You will lose your balance!)

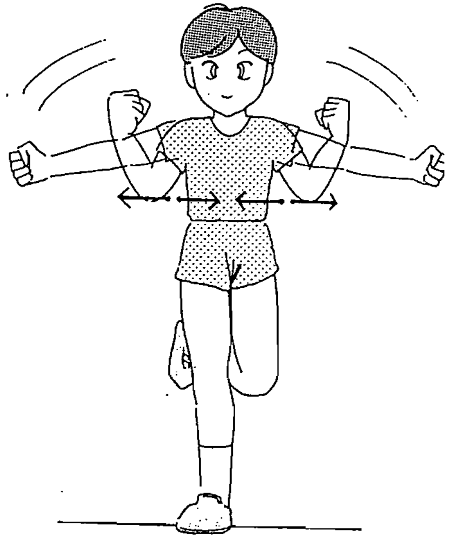


Figure 2: What if you thrust both arms in opposite directions? (You can secure a stable and forceful motion.)

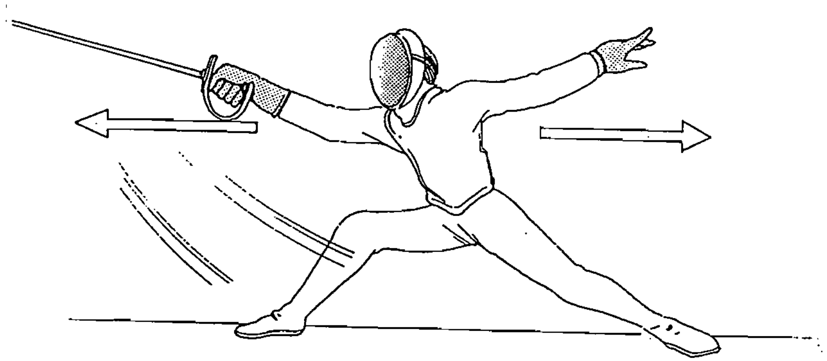


Figure 3: A hit in fencing (The hit can be intensified by movement in the opposite direction.)

Chapter 2
Sports Movements: Rotations Around an Axis

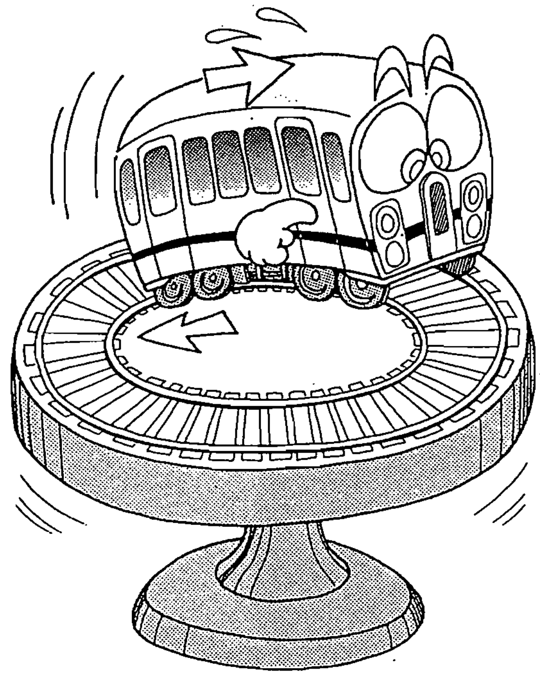
Quiz: What will happen if a train moves around on a round table that can rotate freely?

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 can not 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).

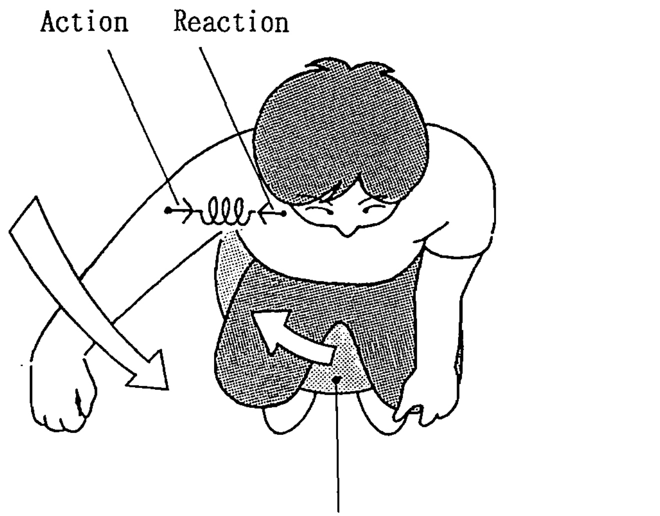


Figure 1: The mechanism of movements of an arm and a body in the opposite directions.

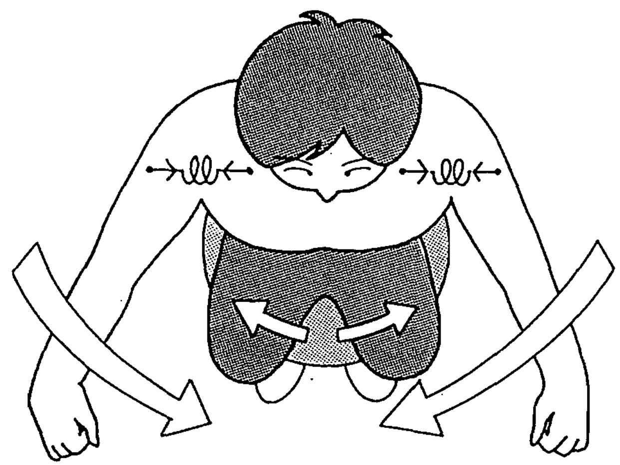


Figure 2: What if both arms are simultaneously moved and crossed?

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 torotation 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.

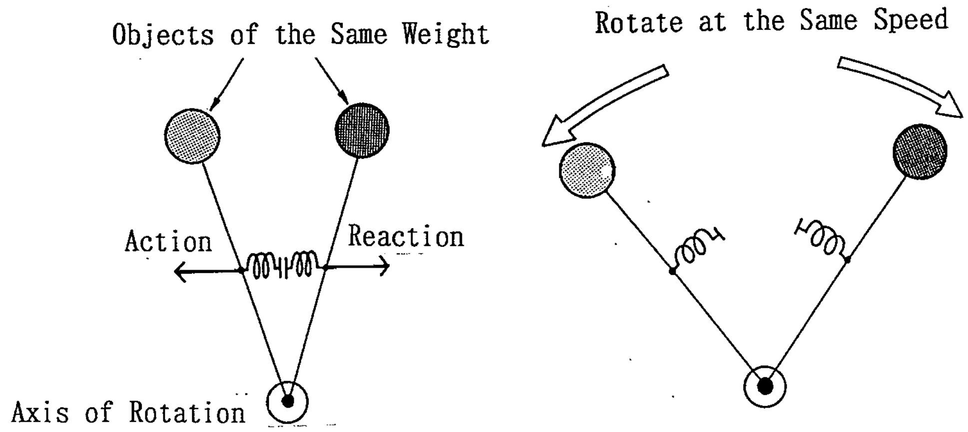


Figure 1: A model for opening arms

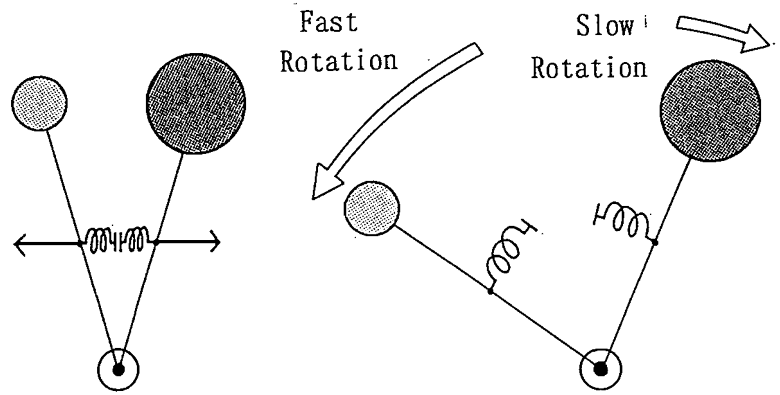


Figure 2: A model for opening arms with a weight in one hand

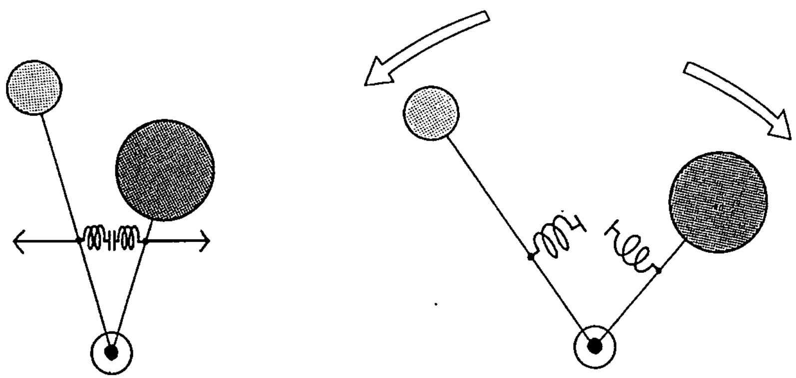


Figure 3: A model for bending the arm with the weight (Keeping the arm closer to the body for a longer time accelerates movement.)

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 a ction 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.

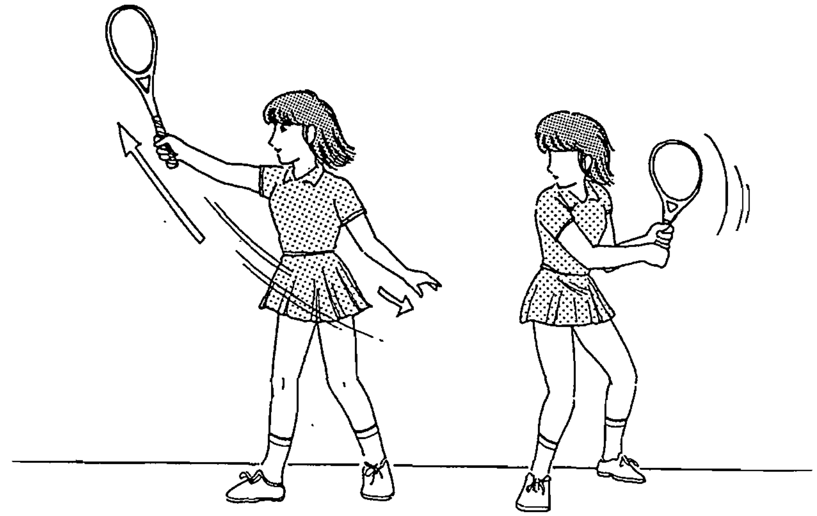


Figure 1: A backhand stroke in tennis (Without pulling back the left arm, the stroke lacks power.)

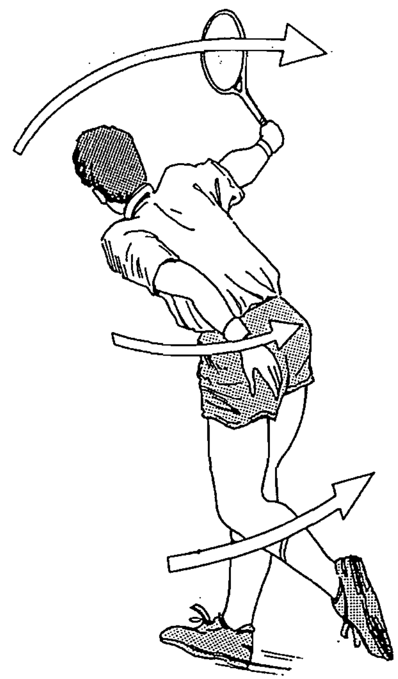


Figure 2: A strong backhand (involving not only the left arm but, amazingly, even the left leg)

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.

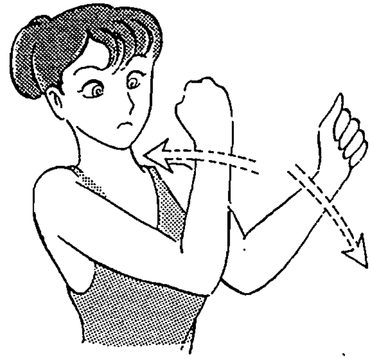


Figure 2: Crossing of only forearms

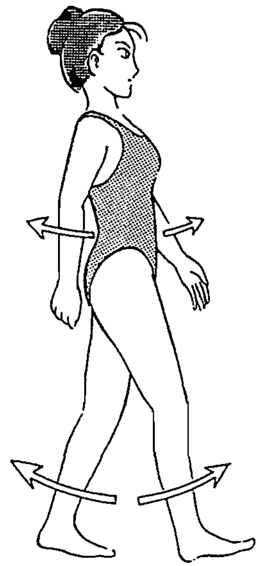


Figure 1: Walking motion

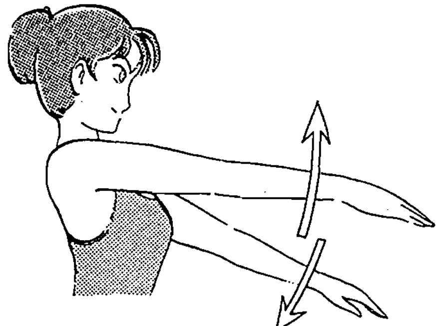


Figure 3: Crossing of both arms

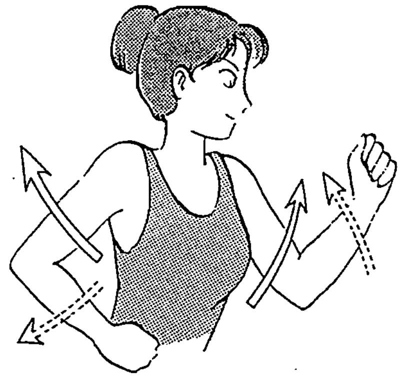


Figure 4: Swinging of both arms

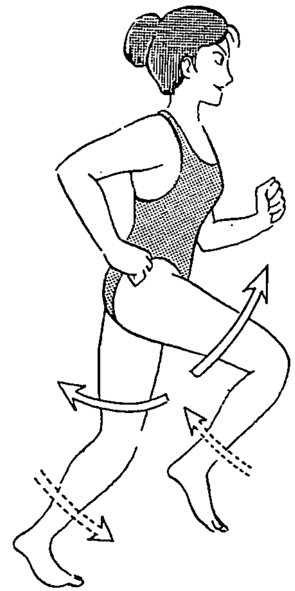


Figure 5: Running motion

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.

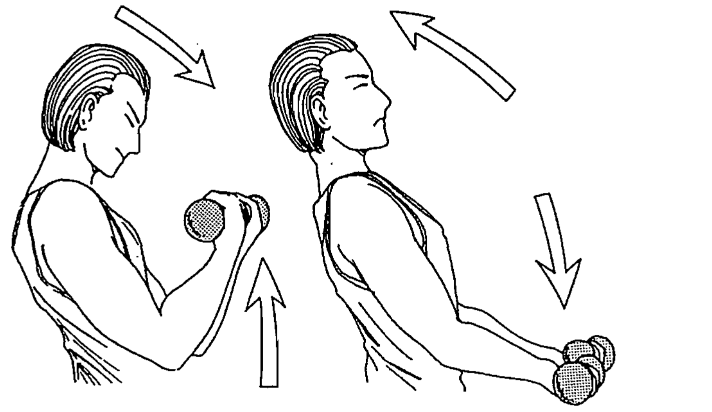


Figure 1: What is necessary for moving arms up and down quickly?

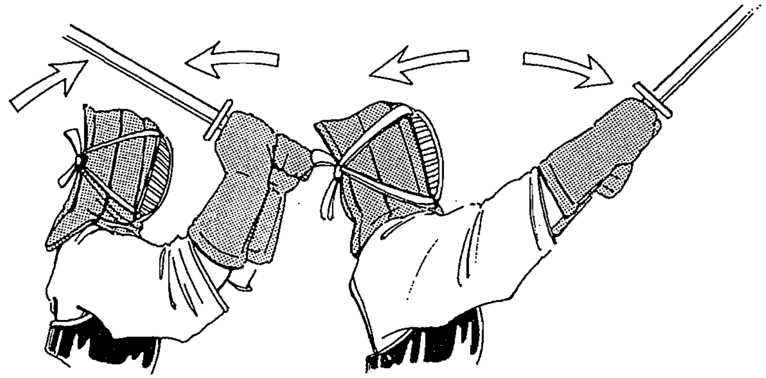


Figure 2: Delivering an effective blow on head in kendo (With the help of your head, you can score.)

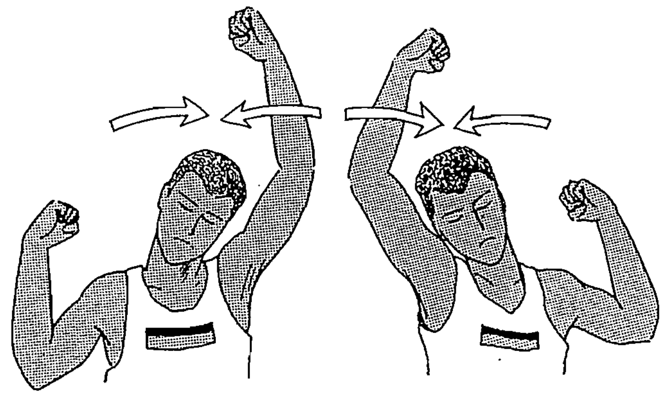


Figure 3: Rotation of the shoulders and neck involve action and reaction effects.

Chapter 3
Sports Movements: Horizontal Rotation

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

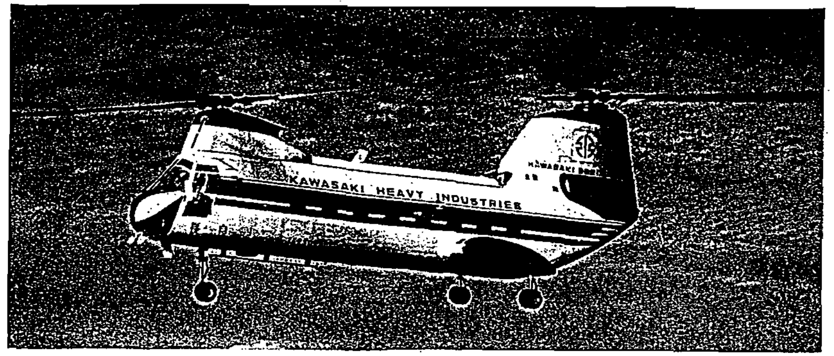
Q: Let's think about rotary bodily movements using the analogy of the principles of a helicopter. Imagine a helicopter with two rotors (Picture 1). Do they rotate in the same direction or in the opposite directions? You might intuitively surmise that the helicopter will maintain a better balance if the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

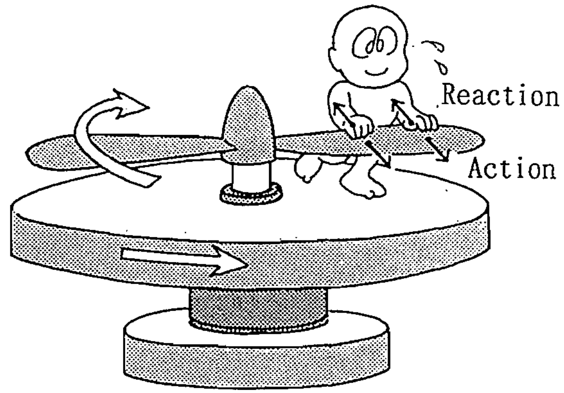


Figure 1: When the upper part is turned, the lower part moves in the opposite direction.

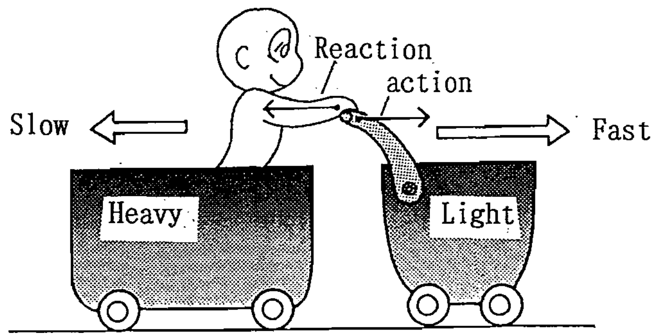


Figure 2: If you push, you are pushed back!

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.

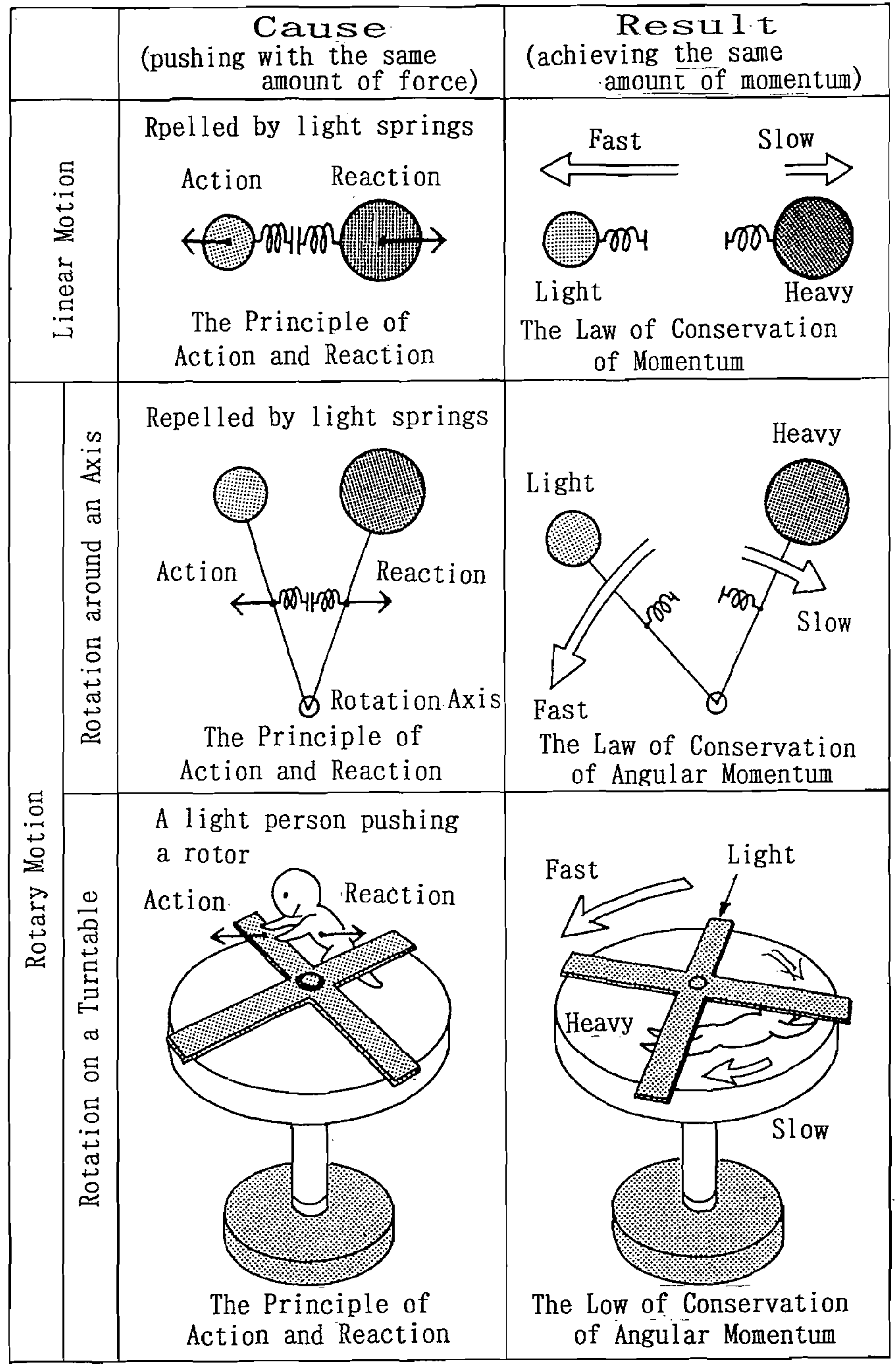
In these cases, two objects first separate from each other, illustrating the action and reaction relationship. Since both objects move with the same amount of momentum, it will always be true that a light object moves fast while a heavy one moves slowly.

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>



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?

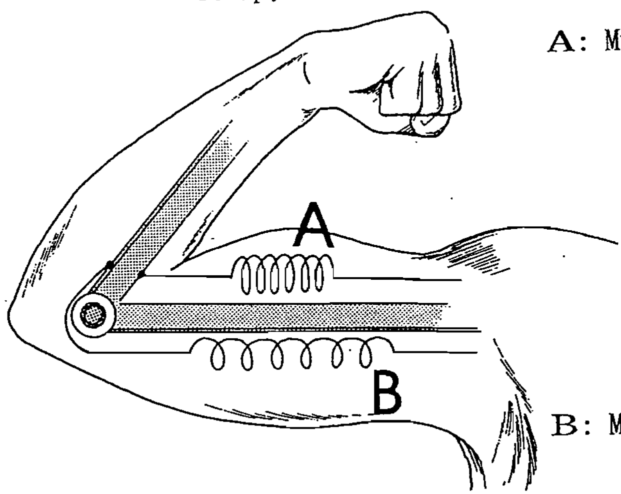
The answer involves muscle functioning: that is, muscles only produce power during contraction, whereas a spring produces power during both contraction and release.

Figure 2 shows the roles of various arm muscles, whose resulting power is generally used to twist the torso. As is evidentfrom 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.

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....

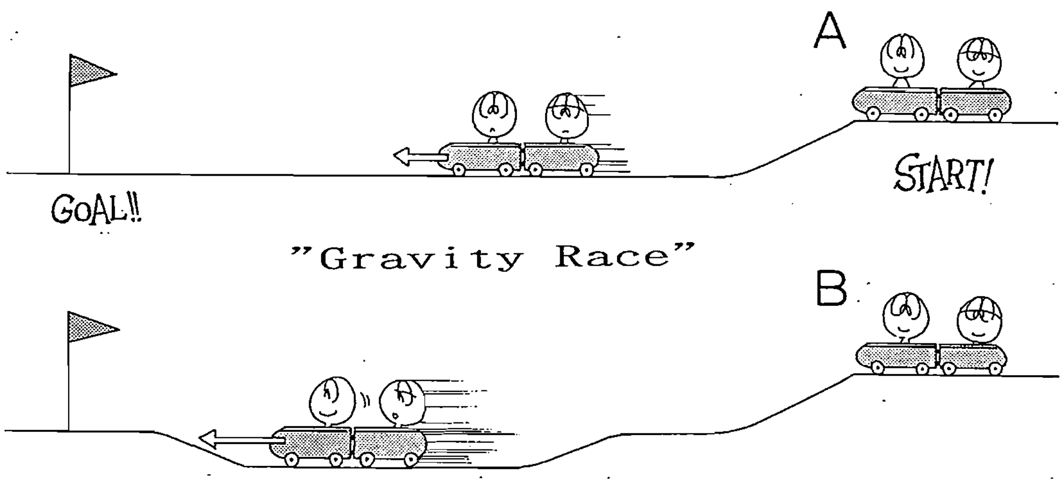
A: ...You might reason that way, but the answer is that B, accelerated on the downhill, will travel through the flat part faster than A and reach the finish before A. Why does this happen?

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?



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?

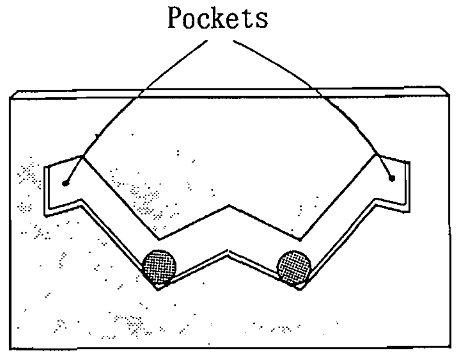
It is easy to put one ball into one pocket, but when you try to sink both balls, one always seems to fall out. What should we do?

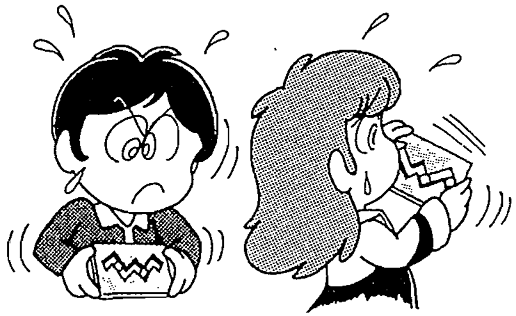
A: The answer is to utilize centrifugal force; which will easily solve this puzzle.

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.

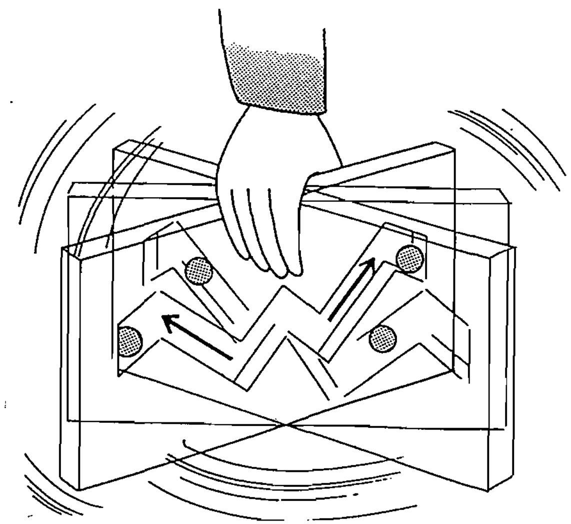
An object tends to go down a downhill slope due to gravity, but when centrifugal force is greater than gravity, it will move up the slope. In this way, centrifugal force works on every rotating object. We may feel it substantially when swinging a bat or moving along a curve.

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.

Chapter 6
Sports Movements: Center of Gravity

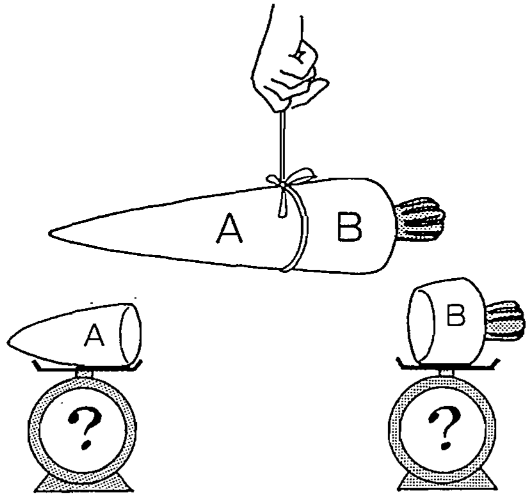
Quiz: Which of the two pieces of a carrot is the heavier?

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.

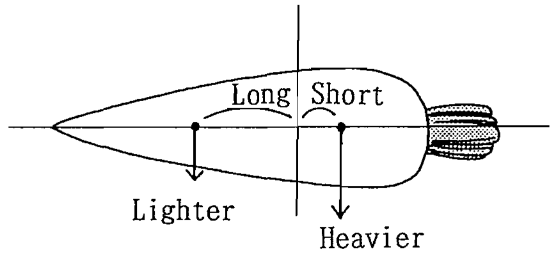
A: The answer is that B is heavier. This is the same as balancing a seesaw: a heavier person sits nearer to the fulcrum and a lighter person sits farther from it. In the case of this carrot, the whole carrot keeps its balance because the weights of separate pieces concentrate on their respective cen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

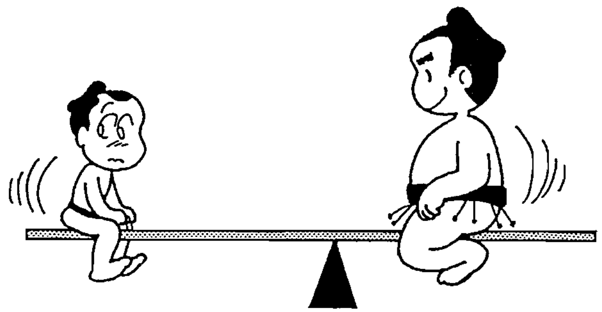
Actual sports movements will not be optimized if one follows the claim that if the lower body is strong and firm, the cente r of gravity will not move. In this chapter, we will think about what happens to the center of gravity in sports movements.



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.

Chapter 7

Sports Movements: How Easy It Is to Turn Around

Quiz: Which of the two wheels rolls faster?

Q: As indicated in Figure 1, there are two wheels (A and B), each of which is made of two discs connected with three iron bars. Both are released from the top of a slope at the same time. A has the three bars placed near the edge of the discs while B has the bars near the centers. Both wheels weigh the same.

Now, which one will roll faster? To answer this question, it is necessary to consider which is easier to roll, or which has its mass concentrated at the center of the wheels.

A: The correct answer is "B rolls faster than A." If you think of a spin in figure skating as in Figure 2, this problem will be easier to comprehend. A person rotates differently when the arms are extended and bent. This (how difficult it is to rotate) is called the "moment of inertia".

In this chapter, to analyze various sports movements related to the moment of inertia, we will use such simpler expressions such as "how easy it is to rotate" or "how difficult it is to rotate". I am sure that you will be able to find some useful hints for everyday sports activities.

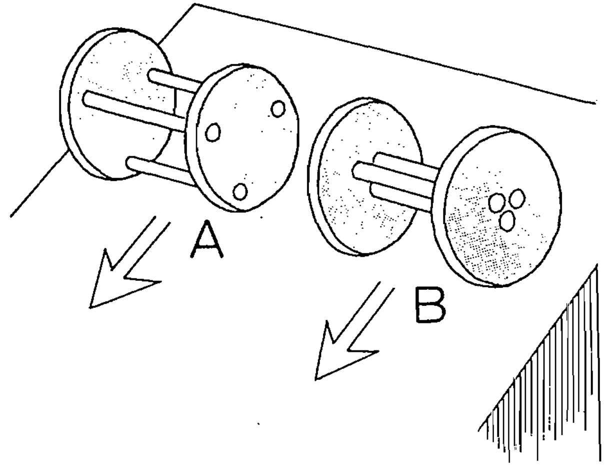
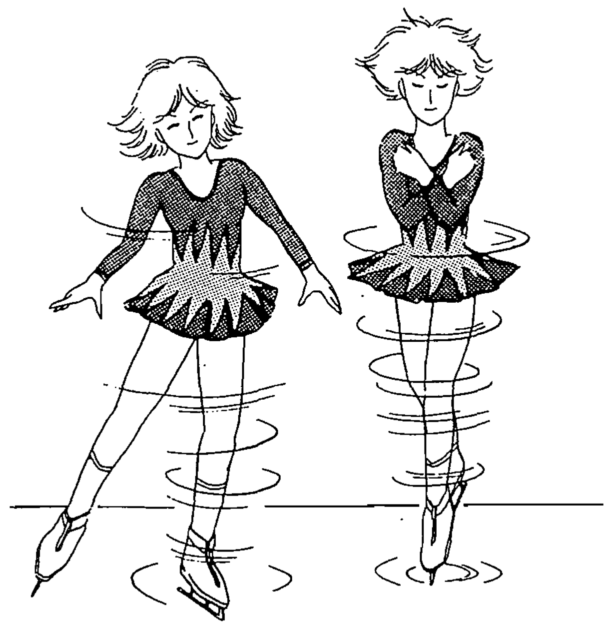


Figure 1: Which of the two wheels rolls faster?



a. Difficult to rotate b. Easy to rotate

Figure 2: Figure skating spins

Chapter 8
Sports Movements: Snaps

Quiz: What will happen if you swing a racket on a turntable ?

Q: Suppose you stand on a turntable, fix your right arm by holding it with your left hand, and swing the racket by only moving the wrist, as shown in Figure 1. In which direction will the table turn? (If you try the same thing without a racket, you will not notice any movement.)

A: The answer is that it will move in "the direction indicated by b in Figure 1". Although only the wrist will seem to move independently, detached from the body, that is not the case. Because both the wrist and the racket are connected through the arm to the body which is supported by the turntable, the body itself will be affected by the movement of the racket. If only the wrist is swung without a racket, the body will not be affected because the weight of the wrist is negligible. However, if it is swung while holding a racket with a certain weight, force will be transmitted through the arm to the body, which is rotating in the opposite direction.

In Chapter 2, we observed that if an arm is swung on a turntable, the body moves in the opposite direction. The same principle can be viewed as working here and moving the body in the opposite direction. Moreover, in either case, a rotary motion will result from the effect of action and reaction.

As indicated in Figure 2, even if you try to throw a ball using only your wrist, the power will be almost negligible. However, snaps can be quite effective for transmitting much greater power. In this chapter, we will look at the transmission of power throughout the body from various angles, and try to prove that seemingly feeble snaps can actually generate great power.

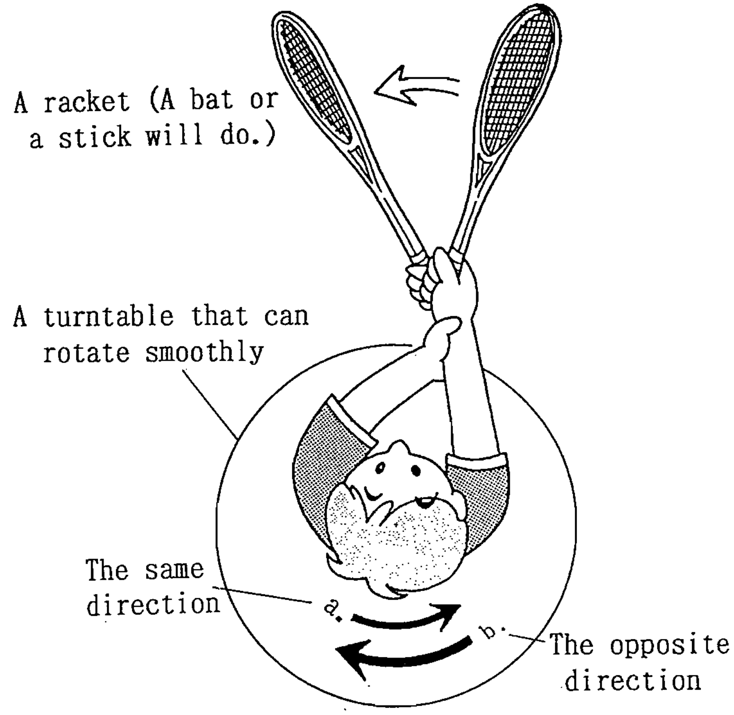


Figure 1: What happens if you swing a racket on a turntable...?

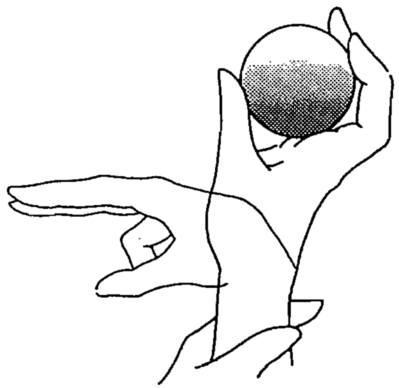


Figure 2: How far can you throw a ball by only snapping your wrist?

59. There are two ways to snap a wrist !

When we hear the word, "snapping," we usually think of the way indicated in Figure 1. But this is not the only snap we use. There are actually two kinds of snaps. Unless we distinguish them from the start, our discussion may be somewhat confusing.

The two kinds of snaps are, of course, a lateral snap and a vertical snap. First, swinging the wrist laterally, or rotating it around the wrist as a pivot as in Figure 1, is called "hinging". A "hinge" is a small part attached to the side of a door. This movement is frequently used in a shoulder pass in basketball (Figure 2), in serving or spiking a volleyball, in pitching a baseball, etc.

The other movement is called "cocking," which means swinging the wrist vertically as in Figure 3. This is typically exhibited in the movement of hitting a nail with a hammer (Figure 4).

In golf, turning the wrist upward is frequently called "cocking"; while turning it downward is called "uncocking". Actually these movements are accompanied by some lateral motion. Otherwise, it would not be possible to move the wrists smoothly.

In any event, these wrist movements are quite frequently found in baseball, golf, kendo, etc., and are characterized by the movement of the hand that resembles the breaking of the wrist downward, as shown in Figure 3c, at the moment of impact.

This occurs because the arm is strongly pulled by a large centrifugal force at the moment of impact, as is usually the case in golf.

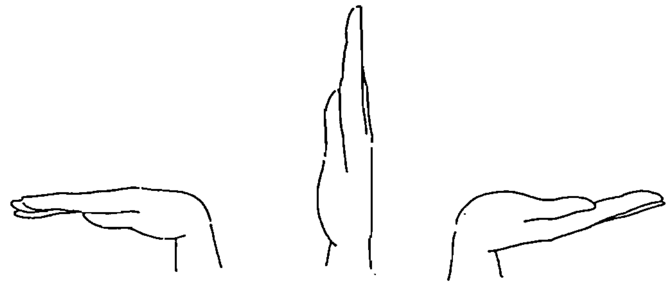


Figure 1: Hinging (lateral rotation of the wrist)

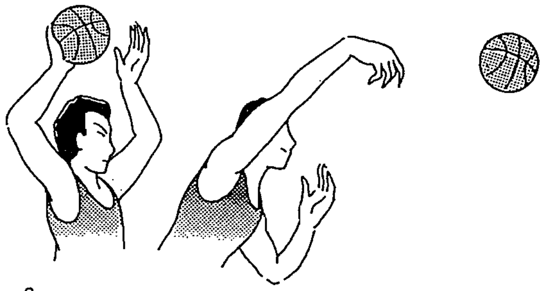


Figure 2: Shoulder pass in basketball

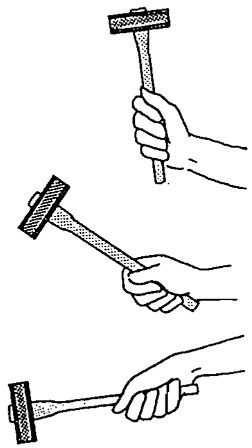


Figure 4: The motion of hitting a nail with a hammer

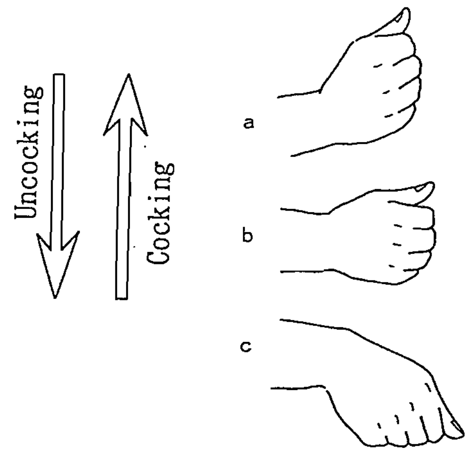


Figure 3: Cocking (vertical rotation of the wrist)

60. Bodily movements can be explained by these models!

Bodily movements seem to be hard to grasp clearly because the body can move quite freely. But there are some common factors looking at a golf swing or a batting motion (Figure 1), we notice that first the lower part of the body, which generates two thirds of a person's physical power, pushes off the ground, leading to a reaction that causes the body to turn. Then that rotation energy is transmitted to the arms, and from there to the club or bat.

In the upper part of the body, in particular, we notice that the power is conveyed in such the order of "torso "* arm "* apparatus". Yet, in order to look into this phenomenon in more detail, we should replace it with a simpler model to make it easier to understand.

In the case of linear motions, we can use a model in which three carts with different weights are pushed with one's legs as in Figure 2. At first, these connected carts move at the same speed.

Starting from this state, first A pushes cart (2); then B pushes cart (3). The final outcome is that only the cart at the top, (3), is accelerated. That is, due to the effect of action and reaction, the pushed cart accelerates.

This could serve as a simple model if we compare the pushing power of A and B to the muscle power of a person, and carts(1), (2), and (3), to the torso, the arm, and the apparatus.

This principle can be also applied to a rotary motion. Figure 3 shows discs of different weight that rotate freely. At the moment a disc is pushed, there is an action and reaction.

However this model is not quite adequate since in the case of rotary motions, the ease of rotation can be changed by bending the arms or the apparatus. This point will be discussed later in greater detail.

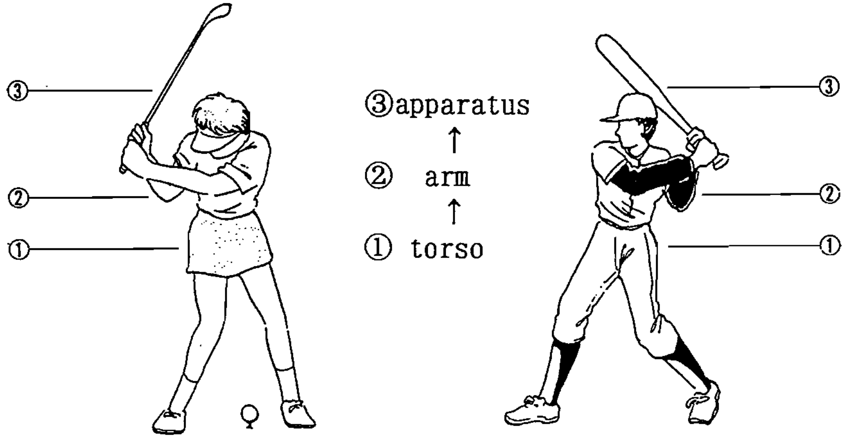


Figure 1: What characteristics do a golf swing and a swing of a baseball bat have in common?

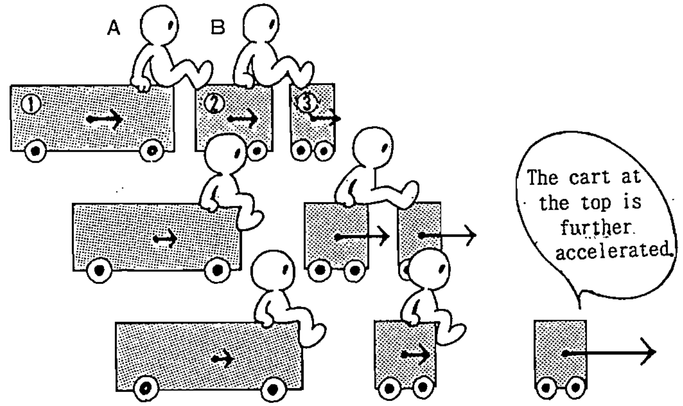


Figure 2: What if the connected carts are pushed one after another?

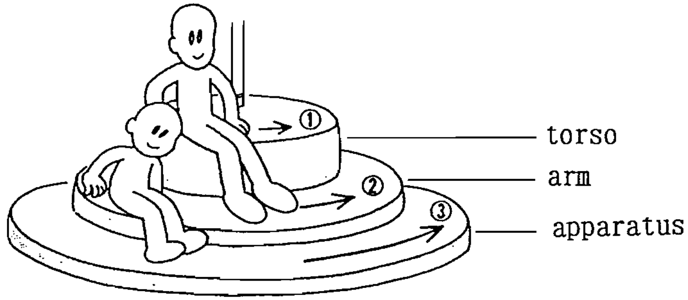


Figure 3: What if rotating discs are pushed one after another ? (Each disc rotates smoothly.)

61. What is the meaning of "Use your body like a whip"?

Although thus far we have compared arm movements to the simple motion of sticks, human arms actually consist of many separate parts. Hands also have fingers with numerous joints.

Figure 1 indicates how the fingers are involved in throwing a ball. The subtle movements of fingers cannot be ignored; the entire movement can be subdivided into tiny parts.

The often heard advice, "Use your body like a whip," can be easily understood by imaging that the force is efficiently transmitted from larger parts ("levers") to smaller ones, with each joint moving flexibly.

Figure 2 shows the mechanism of how a whip works. Although each section alone does not contribute much in terms of strength and magnitude of the movement, if these sections are combined and the force is concentrated on the tip, both the movement and velocity are increased and able to perform a great amount of work.

A wrist may seem feeble, but since it is located on the tip of an arm, or a whip, it can be used to concentrate the force of the entire body. This explains the concept behind the expression, "Snap your wrist when throwing the ball." In golf, the "whip" effect is even more pronounced because the club is bent.

This kind of movement is not only located in the arm or upper part of the body; the entire body or the legs can be involved. As seen in Figure 3, kicking a ball in soccer can be viewed as a kind of rotary motion around the hips.

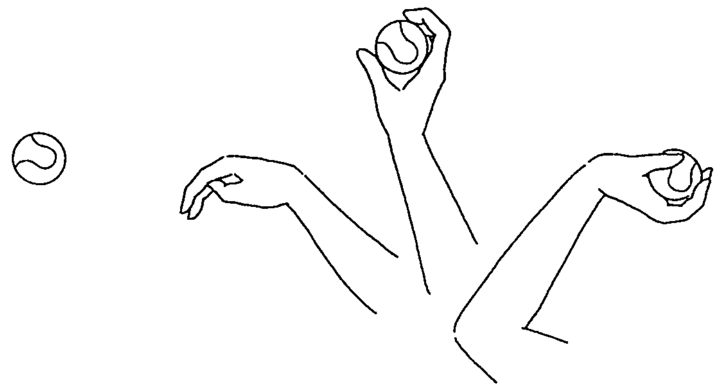


Figure 1: Throwing a baseball with a snapping movement

Figure 3: A soccer kick: Legs move in a rotary motion around the hips (The leg is used like a whip).

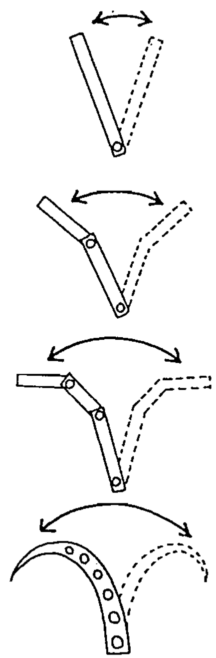


Figure 2: The principle of a whip (A whip is a multi-leveled lever: the magnitude and the velocity of movement increase toward the tip.)

62. You can hammer a nail harder if you stop your hand!

In fact, a whip conveys force through multiple levels. But since it is much easier to think of the mechanism in simpler terms, we will use a two-step model. Let's first look at the " separation" phenomenon in linear and rotary motion.

When two objects separate from stationary positions, they will move in opposite directions. But when two objects moving in the same direction at the same speed separate, as when one object pushes the other (Figure 1), the movements are so complicated that we may miss the subtle dynamics unless we observe them closely. In a light push, cart (2) and disc (2) are ordinarily accelerated, and cart (1) and disc (1) are decelerated.

However, if pushed with an appropriate amount of force, the cart and disk (1) can be stopped, a case which is analogous to ompletely conveying momentum of the body to one's arms or sports equipment.

A simpler example of this case is found in hammering a nail: if you keep your wrist flexible and stop your arm movement immediately before hitting the nail,the hammer will accelerate and the nail can be hit with much more force. This is exactly what occurs in the previous examples. If you draw back your arm a little more, the tip of the hammer will be further accelerated.

What happens if the cart in Figure 1 is pushed with more force? The pushed cart is further accelerated and the pushing unit actually moves in the opposite direction.

Figure 2 depicts figures immediately after impact in baseball and golf. The leaning back of the body in the direction opposite to the flying ball occurs for the reasons presented above. This principle, though not commonly recognized, is actually the secret to hitting a ball harder.

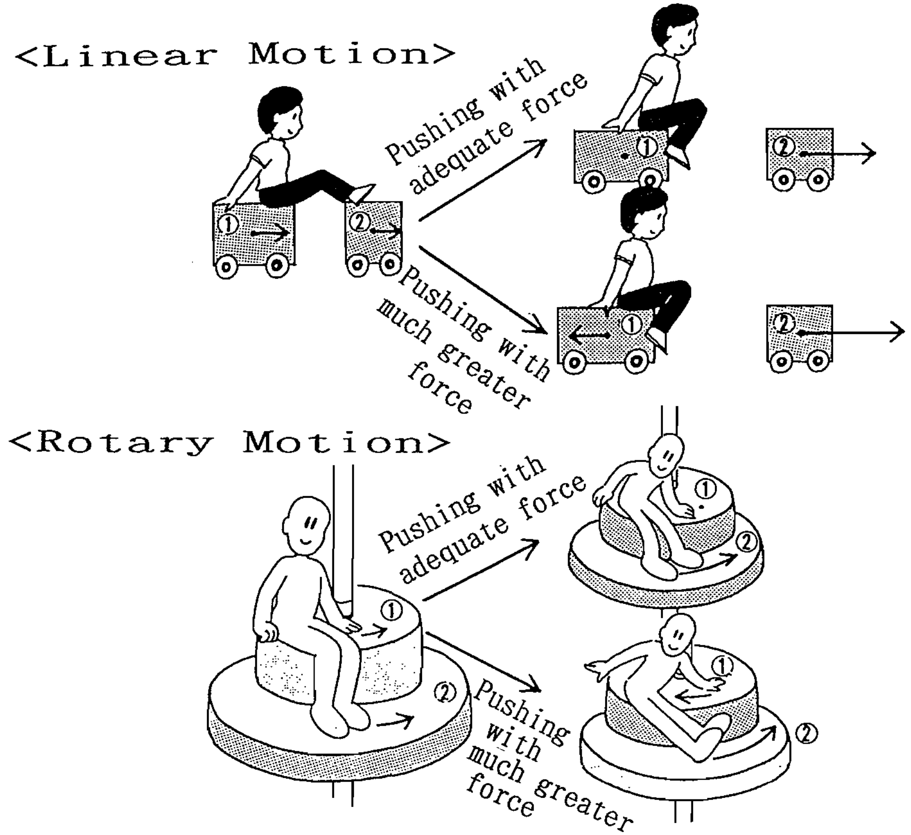


Figure 1: What if two objects moving at the same speed arepushed?

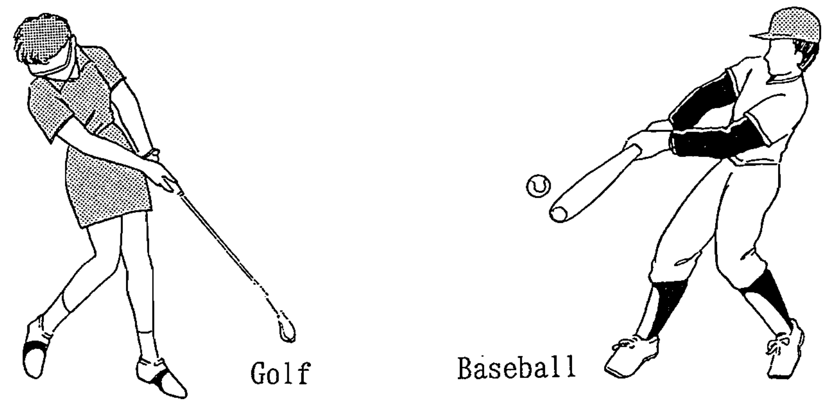


Figure 2: The key is to hit a ball while leaning back.

63. Snapping is "action-reaction"!

In the previous section, it was stated that you can hammer a nail more easily if you pull back your wrist slightly, using the whip principle. This effect is quite noticeable if you try this with a rope. As you swing the rope, releasing the force will stop your wrist; if you start with your wrist in a slightly cocked position, the end of the rope will accelerate with a "swishing" sound.

Thus, one end accelerates as the other end is stopped or moved in the opposite direction. This motion is often called "using a snap," and the entire motion is actually based on the principle of action and reaction. This is quite obvious in Figure 1, which shows the backward motion of the forearm while the hand is moved forward.

Because snapping has the great accelerating effect, it is used in all kinds of sports.

Take a spike in volleyball, for instance. As Figure 2 depicts, a setter tosses the ball, then the spiker quickly jumps up, avoiding the opponents' blocks, and smashes the ball into the opponents' court by controlling his or her wrist.

If the spiking player makes too large an arm movement when close to the net, he or she may inadvertently touch the net. Thus, a snapping movement to pull back the arm slightly is necessary at the moment of the spike.

Figure 3 depicts a jump shot in basketball, which incorporates snapping movement in the fingers as well as the wrist. Such movements supplement jumping power and allow good ball control.

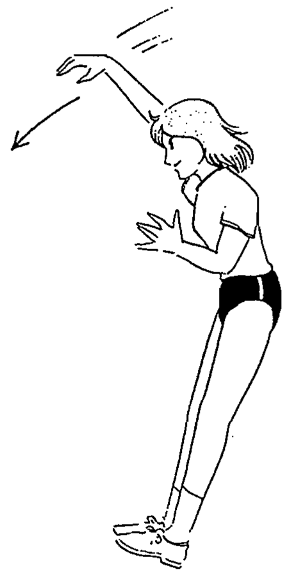


Figure 2: A spike in volleyball (Stop the arm swing and make effective use of snapping the wrist!)

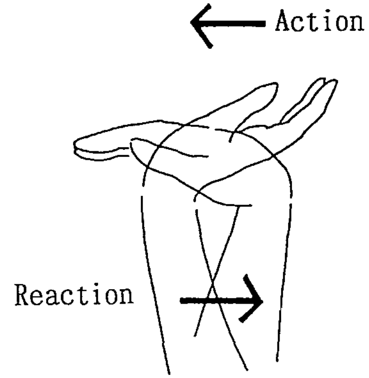


Figure 1: What is a snap really made of?

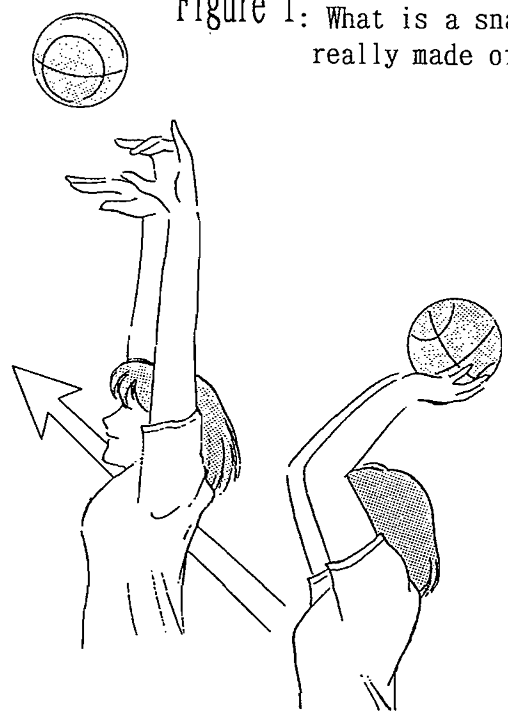


Figure 3: A jump shot in basketball involves snapping both the wrists and fingers.

Chapter 9

Sports Movements: ~~Reactive~~ Rebound Motions

Quiz: How high does a ball bounce when placed above another?

Q: Suppose you drop a ball on the floor. However high it may bounce, it will not bounce back to the original height. What will happen if two balls of different sizes (e.g. a tennis ball and a basketball, shown in Figure 1) are placed one above another and then dropped? The centers of the two ball must be aligned with one another.

A: Let's do it. Although it is very difficult to align the centers of the two balls and make the tennis ball bounce vertically, when this is done, the ball bounce will easily surpass your height (Figure 2). Even if the balls are released only from a height of one meter, the tennis ball may sometimes bounce as high as ten meters.

The big basketball underneath touches the floor first and bounces back; then, the small tennis ball collides with the basketball and receives the basketball's kinetic energy. As a result. the tennis ball can bounce up much higher than the original dropping point; meanwhile, the basketball's bounce becomes almost negligible. As this example demonstrates, if the energy derived from the bounce of one object is properly utilized, another object can perform much greater work than originally expected.

The principle described above loosely demonstrates sports movements that maximize our muscle power potential by utilizing motions that oppose originally intended direction, then quickly return.

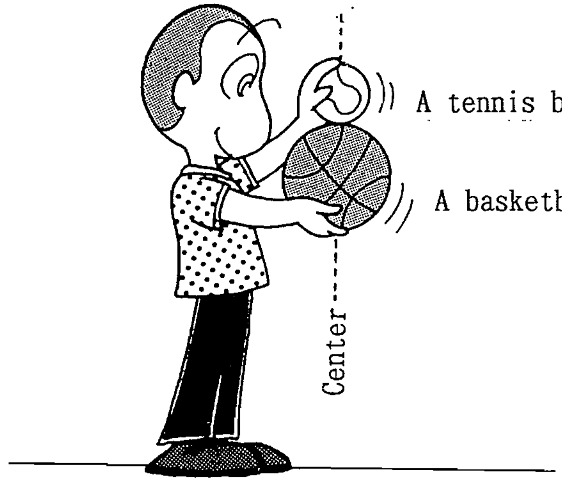


Figure 1: How high does it bounce?

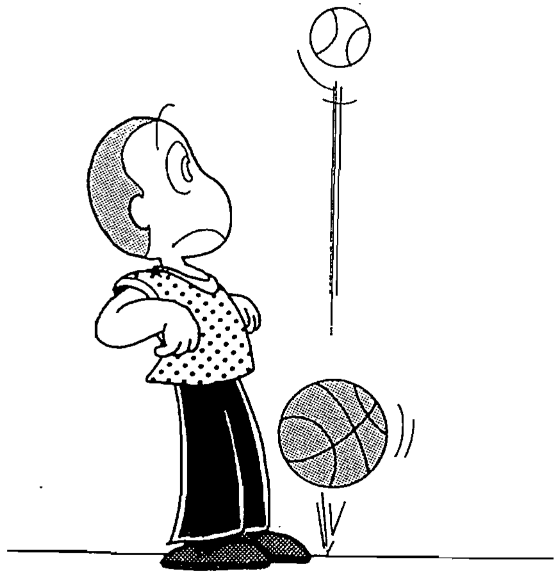


Figure 2: Receiving kinetic energy from the bigger ball, the smaller ball can bounce up to surprising heights.

Epilogue

The key phrase is still "action and reaction".

At the outset of this book, we introduced several motions for throwing a ball as far as possible, in which we noticed that some parts of the body always move in the direction opposite to the flight of the ball. This phenomenon is likely the most common and essential of all sports movements. We developed a series of arguments and explanations based on this assumption.

Particularly in sports where kicking, hitting, or throwing a ball is essential, moving the center of gravity at the moment of the impact causes a tremendous loss of energy. Therefore, balance is maintained by moving lighter parts of the body, such as the arms, in the opposite direction.

In other words, the physical mechanism at work is the Principle of Action and Reaction. The body movement that maximizes this principle is the "snap".

In sports that do not use a ball, the same principle can explain body movements quite readily, and be used to maximize athletic performance.

A long-held maxim in the academic world goes, "Good theories are always simple." This book introduces one of the most basic principles in physics, the Principle of Action and Reaction, to clarify various sports movements. Though you may have been bewildered at first, as we explored various factors in many sports movements, we returned to this simple and compact form.

In the history of physics, there was a time when Newton's theories were touted as being capable of explaining every physical phenomena around us. But actually his theories have limitations and they were replaced by Einstein's theories, which include those of Newton. Now there is a move to find limitations even in the theories of Einstein.

Taking all this into consideration, remember that "theories" are nothing more than models to explain innumerable phenomena, and they tend to have intrinsic limitations.

This book has introduced several models, which, of course, have limitations and will likely be absorbed by more comprehensive and broader theories some day. Yet, at present, I believe that the Principle of Action and Reaction is a useful tool as a simple, easy-to-understand framework to analyze various sports movements.

I sincerely hope that you will be able to use this work to improve your skills and techniques in as many sports as possible.