were to lean in any direction, this would shift the perpendicular from the centre of gravity higher than usual, because of the head-load, outside the base and unbalance them.

Back now to the problem I set you at the beginning of the chapter. The sitting boy's centre of gravity is inside the body near the spine—about 20 centimetres above the level of his navel. Drop a perpendicular from this point. It will pass through the chair behind the feet. You already know that for the man to stand up it should go through the area *taken up by the feet*. Consequently, when we get up we must either bend forward, to shift the centre of gravity, or shove our feet beneath the chair to place our "base" below the centre of gravity. That is what we usually do when getting up from a chair. If we are not allowed to do this, we'll never be able to stand up—as you have already gathered from your own experience.

Fig. 16. When one stands, the perpendicular from the centre of gravity passes through the area bound by the soles of one's feet

WALKING AND RUNNING

The things you do thousands of times a day, and day after day all your life, ought to be things you have a very good idea about, oughtn't they? Yes, you will say. But that is far from so. Take walking and running, for instance. Could anything be more familiar? But I wonder how many of you have a clear picture of what we really do when we walk and run, or of the difference between the two. Let's see what a physiologist has to say about walking and running. I'm sure most of you will find his description startlingly novel. (The passage is from Prof. Paul Bert, *Lectures on Zoology*. The illustrations are my own.)

"Suppose a person is standing on one leg, the right leg, for instance. Suppose further that he is lifting his heel, meanwhile bending forwards. [When walking or running a person exerts on the ground, when pushing his foot away from it, a pressure of some 20kg in addition to his weight. Hence a person exerts a greater pressure on the ground when he is moving than when standing.—*Y. P.*] In such a position the perpendicular from the centre of gravity will naturally be outside the base and the person is bound to fall forwards. Scarcely has he started doing this than he quickly throws forward his left leg, which was suspended thus far, to put it down on the ground in front of the perpendicular from the centre of gravity. The perpendicular thus comes to drop through the area bound by the lines linking the points of support of both feet. Balance is thus restored; the person has taken a step forward.

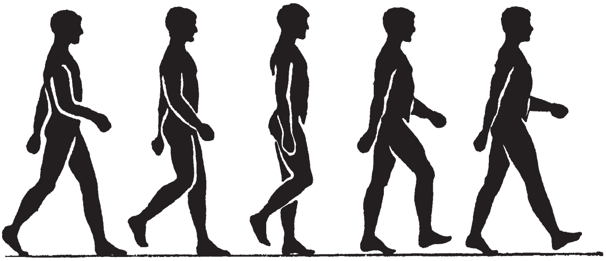

Fig. 17. How one walks. The series of positions in walking

"He may remain in this rather tiring position, but should he wish to continue forward, he will lean still further forward, shift the perpendicular from the centre of gravity outside the base, and again throw his leg—the right one this time—forwards when about to fall. He thus

B

Fig. 18. A graph showing how one's feet move when walking. Line *A* is the left foot and line *B* is the right foot. The straight sections show when the foot is on the ground, and the curves—when the foot is in the air. In the time-interval *a* both feet are on the ground; in the time-interval *b*, foot *A* is in the air and foot *B* still on the ground; in the timeinterval *c* both feet are again on the ground. The faster one walks, the shorter the time-intervals *a* and *c* get (compare with the "running" graph in *Fig. 20*).

takes another step forward. And so on and so forth. Consequently, walking is just *a series of forward fallings*, punctually forestalled by throwing the leg left behind into a supporting position.

Fig. 19. How one runs. The series of positions in running, showing moments when both feet are in the air

"Let's try to get to the root of the matter. Suppose the first step has already been made. At this particular moment the right foot is still on the ground and the left foot is already touching it. If the step is not very short the right heel should be lifted, because it is this rising heel that enables one to bend forward and change one's balance. It is the heel of the left foot that touches the ground first. When next the entire sole stands on the ground, the right foot is lifted completely and no longer touches the ground. Meanwhile the left leg, which is slightly bent at the knee, is straightened by a contraction of the femoral triceps to become for an instant vertical. This enables the half-bent right

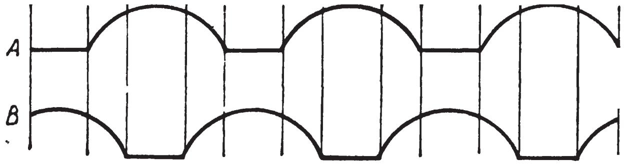

Fig. 20. A graph showing how one's feet move when running (compare with *Fig. 18*). There are time-intervals (*b*, *d* and *f*) when both feet are in the air. This is the difference between running and walking

leg to move forward without touching the ground. Following the body's movement the heel of the right foot comes to touch the ground in time for the next step forwards. The left leg, which at this moment has only the toes of the foot touching the ground and which is about to rise, goes through a similar series of motions.

"Running differs from walking in that the foot on the ground is energetically straightened by a sudden contraction of its muscles to throw the body forwards so that the latter is *completely off the ground for a very short interval of time.* Then the body again falls to come to rest on the other leg, which quickly moves forward while the body is still in the air. Thus, running consists of a series of *hops* from one foot to the other."

As for the energy a person expends in walking along a horizontal pavement it is not at all nil as some might think. With every step made, the centre of gravity of a walker's body is lifted by a few centimetres. A reckoning shows that the work spent in walking along a horizontal path is about a fifteenth of that required to raise the walker's body to a height equivalent to the distance covered.

HOW TO JUMP FROM A MOVING CAR

Most will surely say that one must jump forward, in the direction in which the car is going, in conformity with the law of inertia. But what does inertia have to do with it all? I'll wager that anyone you ask this question will soon find himself in a quandary, because according to inertia one should jump backwards, contrary to the direction of motion. Actually inertia is of secondary importance. If we lose sight of the main reason why one should jump forwards—one that has nothing to do with inertia—we will indeed come to think that we must jump backwards and not forwards.

Suppose you have to jump off a moving car. What happens? When you jump, your body has, at the moment you let go, the same velocity as the car itself—by inertia—and tends to move forwards. By jumping forwards, far from diminishing this velocity, we, on the contrary, increase it. Then shouldn't we jump *backwards*—since in that case the velocity thus imparted would be *subtracted* from the velocity our body possesses by inertia, and hence, on touching the ground, our body would have less of a toppling impetus?

But, when one jumps from a moving carriage, one always jumps forwards in the direction of its movement. That is indeed the best way, a time-honoured one, and I strongly warn you against trying to test the awkwardness of jumping backwards.

We seem to have a contradiction, don't we? Now whether we jump forwards or backwards we risk falling, since our bodies are still moving when our feet touch the ground and come to a halt. (See "When Is a Horizontal Line Not Horizontal?" from the third chapter of *Mechanics for Entertainment* for another explanation.) When jumping forwards, the speed with which our bodies move is even greater than when jumping backwards, as I have already noted. But it is much *safer* to jump forwards than backwards, because then we mechanically throw a leg forwards or even run a few steps, to steady ourselves. We do this *without thinking*; it's just like walking. After all, according to mechanics, walking, as was noted before, is nothing but a *series of forward fallings of our body, guarded against by the throwing out of a leg*. Since we don't have this guarding movement of the leg when falling *backwards* the danger is much greater. Then even if we do fall forwards we can soften the impact with our hands, which we can't do if we fall on our backs.

As you see, it is safer to jump forwards, not so much because of inertia, but because of ourselves. This rule is plainly inapplicable to *one's belongings*, for instance. A bottle thrown from a moving car forwards stands more chances of crashing when it hits the ground than if thrown backwards. So if you have to jump from a moving car and have some luggage with you, first chuck out the luggage *backwards* and then jump *forwards* yourself. Old hands like tramcar conductors and ticket inspectors often jump off stepping *backwards but with their backs turned to the direction in which they jump*. This gives them a double advantage: firstly they reduce the velocity that the body acquires by inertia, and, secondly, guard themselves against falling on their backs, as they jump with their faces forward, in the direction where they are most likely to fall.

CATCHING A BULLET

The following curious incident was reported during the First World War. One French pilot, while flying at an altitude of two kilometres, saw what he took to be a fly near his face. Trapping it with his hands, he was flabbergasted to find that he had caught a German bullet! How like the tall stories told by Baron Munchausen of legendary fame, who claimed he had caught cannon balls with bare hands! But there is nothing incredible in the bullet-catching story.

A bullet does not fly everlastingly with its initial velocity of 800-900 m/sec. Air resistance causes it to slow down gradually to a mere 40 m/sec towards the end of its journey. Since aircraft fly with a similar speed, we can easily have a situation when bullet and plane will be flying with the same speed, in which case the bullet, in its relation to the plane and its pilot, will be stationary or barely moving. The pilot can easily catch it with his hand, especially if gloved, because a bullet heats up considerably while whizzing through the air.

MELON AS BOMB

We have seen that in certain circumstances a bullet can lose its "sting". But there are instances when a gently thrown "peaceful" object has a destructive impact. During the Leningrad-Tiflis motor run in 1924, Caucasian peasants tossed melons, apples, and the like at the racing cars to express their admiration. However, these innocuous gifts made terrible dents and seriously injured the motorists. This happened because the car's velocity added to that of the tossed melons or apples, transforming them into dangerous projectiles. A ten-gramme bullet possesses the same energy of motion as a 4kg melon thrown at a car doing 120 km.p.h. Of course, the impact of a melon is not the same as the bullet's since melons, after all, are squashy.

When we have super-fast planes doing about 3,000 km.p.h.—a bullet's approximate velocity—their pilots may chance to encounter what we have just described. Everything in the way of a super-fast aircraft will ram into it. Machine-gun fire or just a chance handful of bullets dropped from another plane will have the same effect; these