# THE DYNAMICS OF WALKING*

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What makes us walk? When we go at a constant speed, things seem simple, the forces acting on the walking man are balanced — hence the uniform motion. But is it really uniform? What role do the forces at the contact point between a foot and the ground play in a human walking? Can you explain the mechanism of human movement based on school physics? From what moment do we describe approximations of factual errors when describing motion? Two tools were used to analyze the movement of the walking man: a video analysis software — Tracker and a smartphone application — Phyphox. Every move was recorded using at the same time both techniques. This method allows a qualitative analysis of the movement of a walking person, using an equipment available to an average student.

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## 1. Restrictions in the description

In school practice, the analysis of physical phenomena, out of necessity, must be limited to situations in which we do not have to use differential calculus. So how do you deal with the exact description of the movement? For example, in the strict definition of velocity, we use a derivative and in addition it is a derivative of vector size. Requiring too strict definitions often results in not understanding them by students. The way out of this situation might be taking the advantage of the fact that students have some life experience with using this physical quantity. In everyday life, they use different types of speedometers. The speedometer indications can be considered as the instantaneous velocity value. It is enough to make students aware of how this measurement takes place, as it is usually the measurement of a distance traveled by a vehicle over a period of time. From here, it is easy to define velocity.

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Velocity is a vector quantity. The directions of the velocity vector are consistent with the direction of the displacement. The velocity value is determined by the instantaneous sections of the path traveled by the body. It can be even simpler: velocity is a measure of change in the body position. It is similar with acceleration. Acceleration is a measure of velocity changes. The acceleration vector is better understood by students when it is related to the direction of the resultant force on the body. In school practice, students often find it difficult to understand the relation between the acceleration vector and the change of velocity. The association of the body acceleration vector with the resultant vector causing the movement of this body enables students to better understand the issues related to the movement.

## 2. Measuring methods

To describe motion, we should use IT tools. The concept of derivative is not very approachable for many students, fortunately the change in a physical quantity is accepted by them very naturally. It is enough that we find changes in the position (distance traveled) of a moving object, taking place at certain intervals and we will be able to determine the velocity values. Two methods were used to determine the forces acting on a walking man.

Position changes can be determined by using a video analysis software. For example, the Tracker software [1]. This is a free software for analyzing data from video files. From this software, we can get changes in the location of the object from frame to frame in the film. All we need to do is to transfer this data to a spreadsheet. The position changes over time are, in this case, recorded in a form of two columns. The velocity at a given time can be found by subtracting from each other contents from two successive cells in the position change column and dividing by the differences of contents from two successive cells in the time-change column. This way, students who do not know derivatives can determine instantaneous velocity values. However, to analyze the forces acting on a walking man, we need to know about acceleration changes. Acceleration can be found in a similar way to how we found the velocity. Acceleration at a given time can be found by subtracting from each other contents from two successive cells in the velocity column, and dividing by the differences of contents from two consecutive cells in the time-change column. It should be kept in mind that this procedure is a subject to errors resulting, among others, from the inaccuracy of determining position changes.

Direct acceleration measurement can be done by using a smartphone application Phyphox. This application collects readings in real time from the accelerometer that comes with every smartphone. The smartphone made 100 acceleration measurements per second. Measurements were made independently in the horizontal direction along the movement and in the vertical

direction. This smartphone has been attached to the walking body in such a way that the accelerometer can be considered compatible with the actual acceleration of the walking man. A stationary camera was set up a few meters from the road. The measuring system is shown in Fig. 1. The camera's optical axis was perpendicular to the movement of a walking person. The camera recorded 50 frames per second.

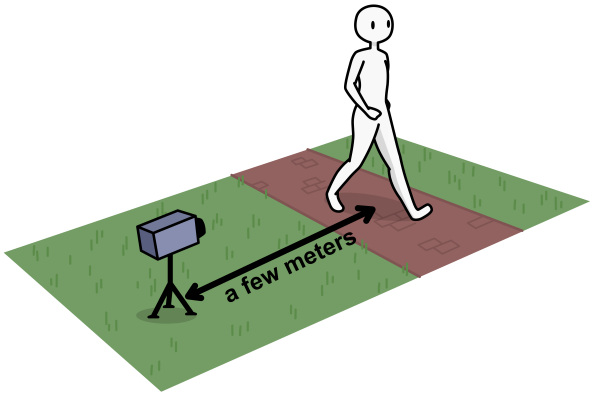


Fig. 1. Diagram of the measuring system.

To analyze changes in the position of a walking person, we need to select the right point on his body. There are problems with choosing such a point. The best measure would be at the mass center of a man, but this point is in such a place that during the walk it is obscured by the hand of the walker. The attempt to analyze a point slightly lower, near the hips, was also not the best idea, the results indicated that the movement was not symmetrical. The part of the hip closer to the camera moved at a different acceleration than the part further away. Finally, the ear point was chosen to be the best one to analyze.

## 3. Measurements

Figure 2 presents the results of the analysis of changes in the position of a point located on the walking person's body.

At the first approximation, it can be concluded that the position changes obtained from the film analysis along the horizontal axis indicate a movement at a constant speed. After applying the method described in the first part, the dependence of acceleration in the horizontal direction on the time shown in Fig. 3 was obtained.

At the same time, the walking man had enabled direct acceleration measurement. Figure 4 shows relations to the horizontal acceleration time obtained from the Phyphox application.

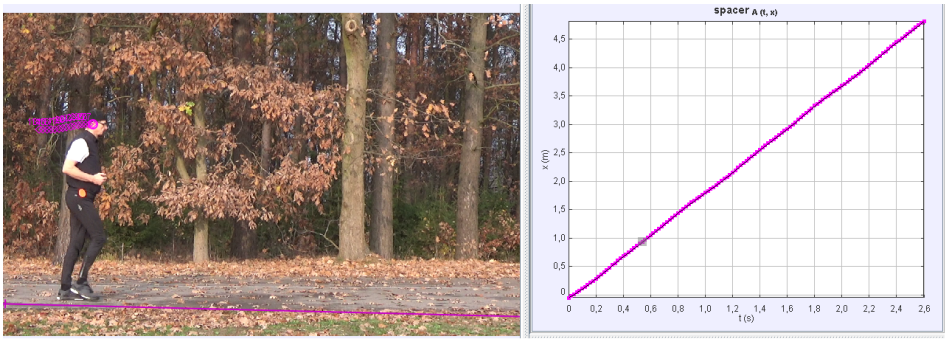


Fig. 2. Results of the analysis of changes in the position of a point located on the walking person's body.

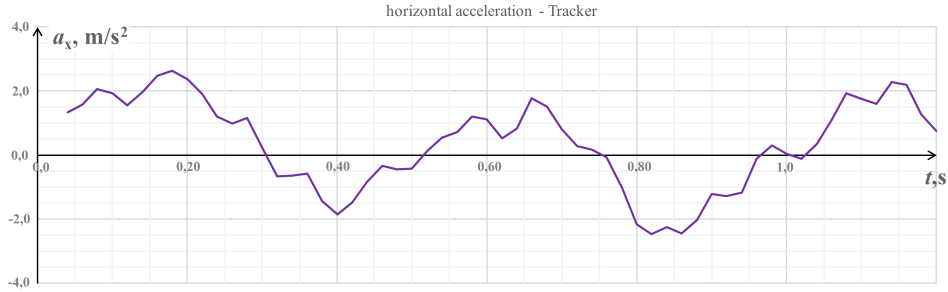


Fig. 3. Dependence on the time of acceleration in the horizontal direction obtained from the analysis of position changes.

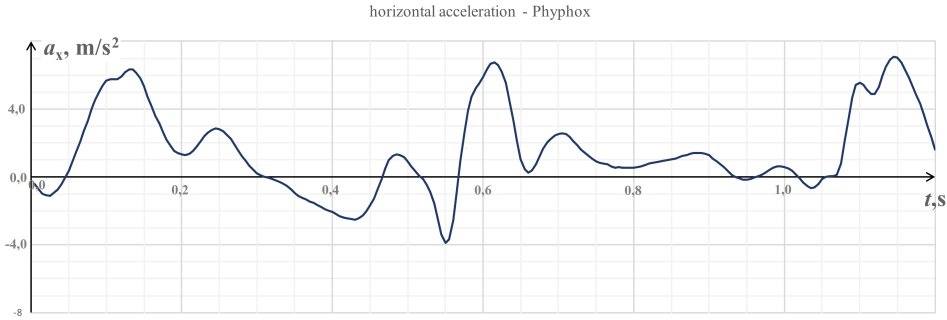


Fig. 4. Dependence on the time of acceleration in the horizontal direction obtained from the Phyphox application.

Comparing the qualitative results obtained from body point movement analysis and from the direct acceleration measurements, it revealed that they are similar. A seemingly uniform motion of a man walking at a constant speed turned out to be a variable motion.

The vertical acceleration obtained by this two methods is also similar. Figures 5 and 6 show the dependence on the time of acceleration in the horizontal direction obtained using the Tracker software and the Phyphox application.

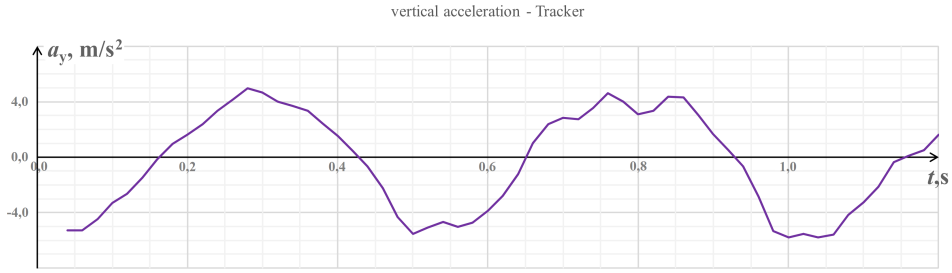


Fig. 5. Dependence on the acceleration time in the vertical direction obtained from the Tracker software.

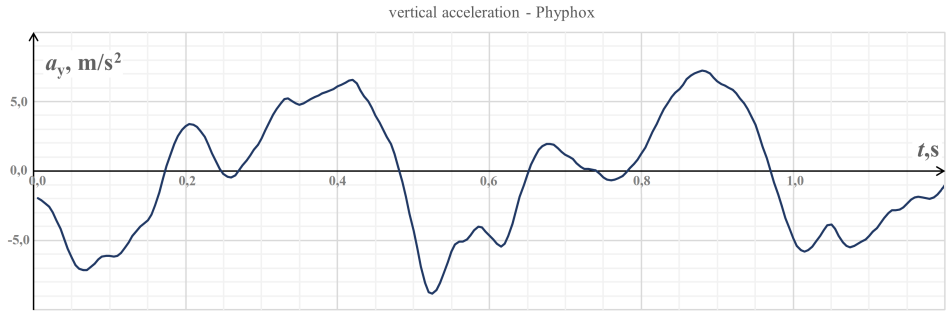


Fig. 6. Dependence on the time of acceleration in the vertical direction obtained from the Phyphox application.

In terms of quality, the results obtained with both methods are similar to those obtained with the help of platforms enabling direct measurement of human forces during the march, see Geyer *et al.* [2] and [3]. From a didactic point of view, this is valuable information. It is hard to expect that schools will have equipment enabling professional measurements of human forces during a march. Described method allows a qualitative description of the walking person using equipment available to every student.

## 4. Qualitative analysis

Figure 7 shows a simplified diagram of the forces acting on a person during the march. Only horizontally directed forces are indicated. In this figure, three phases of the walking human movement have been associated

with the horizontal acceleration graph. The foot remaining behind pushes the ground away. According to the 3rd dynamic principle, the ground pushes the foot forward. In this phase of approximately 0.3 seconds, the movement is accelerated. At the moment when both feet are in contact with the ground, the forces acting horizontally on the human are balanced. The foot in front is pushed back and the foot in back is pushed forward. After detaching the back foot from the ground, there is a phase of decelerated movement. The foot is pushed backwards by the ground.

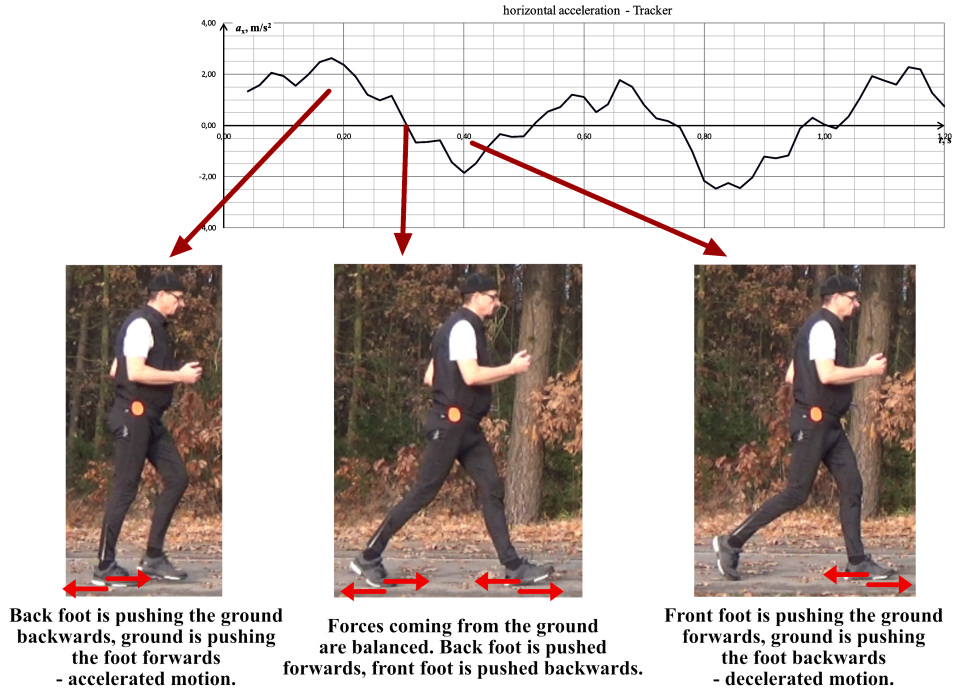


Fig. 7. Phases of a men's walk and his acceleration.

## 5. Summary

It turned out that the knowledge and skills acquired during physics lessons at school allow a qualitative analysis of the movement of people walking. However, it was possible after using IT methods. Perhaps the usage of a camera with a higher time resolution would allow more accurate analysis of the movement. The experience of filming a person walking on a professional platform for measuring forces would allow checking if the method is suitable for quantitative analysis of forces acting on a walking person.

## REFERENCES

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