

Gait Analysis by High School Students

André Heck¹ and Caroline van Dongen²

¹AMSTEL Institute, University of Amsterdam, Amsterdam, The Netherlands, heck@science.uva.nl

²St. Antoniuscollege, Gouda, The Netherlands, caroline_van_dongen@hotmail.com

Abstract

Human walking is a complicated motion. Movement scientists have developed various research methods to study gait. This paper describes how a high school student collected and analyzed high quality gait data in much the same way movement scientists do via recording and measurement of motions with a video analysis tool and via electromyography, i.e., measurement of muscle activity. Physics, biology, and mathematics come together in this practical investigation work at a rather high level. It shows that science learning at school can resemble science practice in research labs, provided that students have adequate tools.

Normal Walk Cycle

Normal walking is a periodic movement of each foot from one position of support to the next position of support in the direction of progress. The gait cycle or stride is defined as the period from one foot strike to the next foot strike of the same foot. Figure 1 illustrates the two phases of the gait cycle and the main gait events.

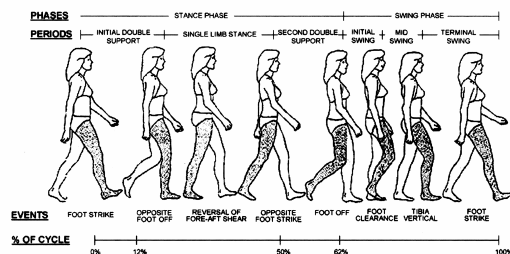


Figure 1. Normal walk cycle illustrating the events of gait (Rose and Gamble¹).

Motion Analysis

Motion analysis is the science of analyzing video clips of body and body part motions in order to study the kinematics and the forces involved. The availability of affordable digital video and computer technology offers students the opportunity to actively engage in motion analysis. Educational projects that meet this learning goal have been reported.²⁻³ In these projects, students conduct all aspects of motion analysis: they formulate research questions about a self-selected human motion, design experiments, carry out video data collection and data analysis, and finally interpret and report their results.

The gait analysis can be kept relatively simple by modeling only the planar motion of upper and lower part of the leg around the hip and knee joint, respectively. Holt, et al.⁴ have modeled this leg motion during normal walk as a force-driven harmonic oscillator. The angular motion curve of the knee joint is described in this model by a sum of two sine functions in which one frequency is twice as large as the other one. As we will see, our experimental results confirm this.

Another useful tool in gait analysis is the so-called hip-knee cyclogram. Its geometric features characterize gait patterns in a quantitative and objective way. Figure 2 shows the hip-knee cyclogram of a normal equal-level walk. Points marked with an 'o' belong to important events of the stride. As we will see, our experimental results yield similar diagrams.

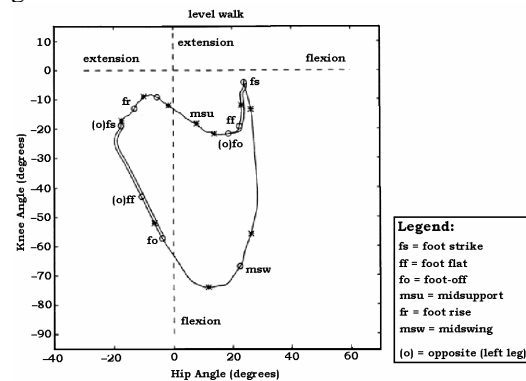


Figure 2. Hip-knee cyclogram of a normal walk (Goswami⁵).

Electromyography

The gait pattern results from the interaction between external forces (joint reaction and ground reaction) and internal forces (produced by muscles and other soft tissue). Muscle activity is typically studied using dynamic electromyography (EMG).^{1,6,7} In case of measurement of activity of superficial muscles, surface electrodes are placed on the skin surface to detect the muscle action potential, i.e., the electric activity responsible for contraction of muscles or muscle groups. Muscle force cannot be estimated directly from the intensity of the signal. Figure 3 illustrates EMG activity during normal walk as simple on-off diagrams for certain muscles. EMG records differ between individuals, and differ for a single individual according to variables such as velocity and muscle force. EMG recording is rather difficult because correct placement of electrodes is critical. Nevertheless, we will see that our experimental results are qualitatively in agreement with results known from the research literature.^{1,6,7}

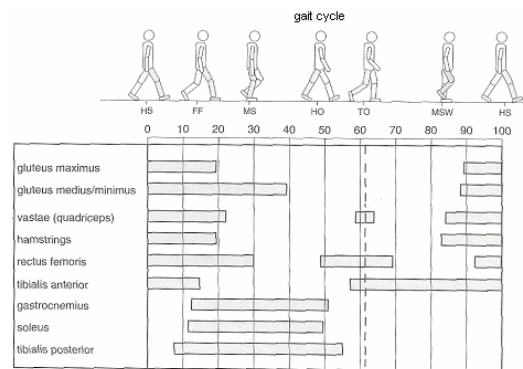


Figure 3. EMG activity during gait (extracted from Deckers & Beckers⁸).

Experimental set up

In the project described in this paper, a high school student studied the motion of the lower limb during normal walking and running at various speeds. The motion was filmed from the side by means of a web cam at 30 frames/sec while the subject was walking on a motor-driven treadmill in the university sport center. The polar coordinates of the hip and ankle joint of one leg with respect to the knee joint were recorded in the video tool of the Coach 6 computer learning environment⁹ (Figure 4). The hip and knee joint angles during a gait cycle were determined from these coordinates. Knee joint angle vs time graphs and hip-knee cyclograms were created and analyzed for walking at various speeds.

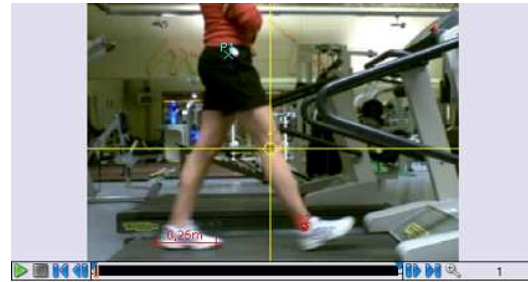


Figure 4. Data recording with the video tool for normal walking at 5 km/h.

Coach 6 allows simultaneous measurement with sensors and video capture. This feature was used in dynamic electromyography during normal walk. EMG data of four muscle groups were obtained at various gait speeds. Surface electrodes were placed in a bipolar arrangement, i.e., two electrodes were placed over a muscle about 2 cm apart and a third electrode was placed at an electrically neutral site. Figure 5 illustrates the locations used for the EMG of the quadriceps femoris, following the recommendations of SENIAM.¹⁰ A sample rate of 900 Hz was used.

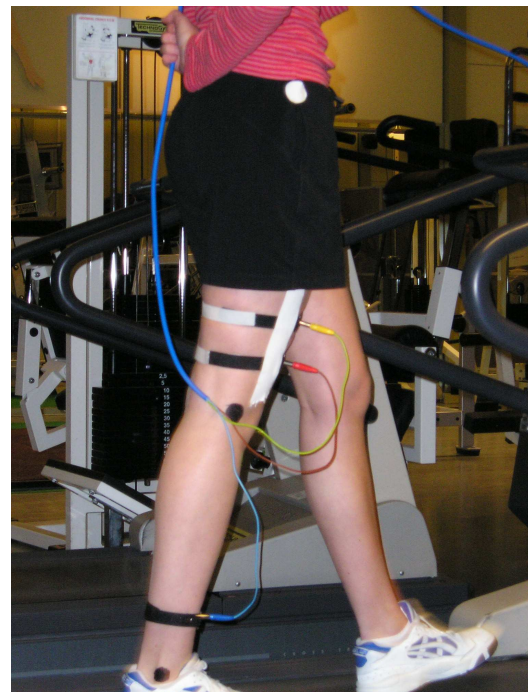


Figure 5. Recording the EMG of the quadriceps femoris during normal walking.

The bipolar arrangement uses an amplifier that consists of three components: a differential amplifier, which records the difference between the two recording electrodes, filtering hardware, and a LED driver that converts the

electric signal into an optical signal. Note that for safety all electrical signals from the human body are coupled optically to the computer. Electrode cream is used in order to minimize contact-resistance of skin and electrodes. Figure 6 shows the EMG equipment, which was originally designed and is still used for recording an electrocardiogram (ECG).



Figure 6. The EMG/ECG set.

The EMG signal can be viewed as a raw signal or it can be further processed. We usually applied first full-wave rectification of the signal, i.e., we took the absolute value of the raw signal with respect to the zero level of the signal. Hereafter we smoothed the rectified signal via a moving average with a time window ranging from 10 to 100 ms.

The video clip, on which one collects spatial and time data, and the mathematical representations like graphs and tables are always synchronized in Coach. This means that pointing at a graph or a table entry automatically shows the corresponding video frame and that selecting a particular frame highlights the corresponding points in diagrams, when the scanning mode is on. This makes scrubbing, i.e., advancing or reversing a clip manually, an effective means to precisely identify and mark interesting events in the video clip and to relate them to graphical features. This feature is regularly used in motion analysis and EMG analysis. We also applied it to link maxima and minima in EMG diagrams with gait events visible in the video clips.

Results

Figure 7 shows the knee joint angle vs. time graph (red points) for normal walking at a speed of 5 km/hr. The diagram also shows the graph of the best function fit with a sum of two sine functions. This fit can be found automatically with the signal analysis tool of Coach 6. The formula obtained is

$$\begin{aligned} \text{knee joint angle} = & 23.6 + \\ & 21.4 \cdot \sin(345 \cdot \text{time} - 9.9) + \\ & 17.9 \cdot \sin(690.4 \cdot \text{time} + 81.5), \end{aligned} \quad (1)$$

where the angle is in degrees. As you see, one of the frequencies is about twice as large as the other. This is in agreement with the model of a force-driven harmonic oscillatory motion of the lower limb during normal walking.

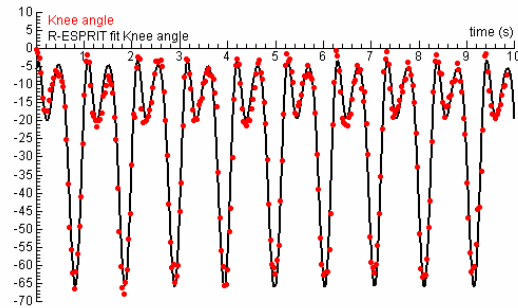


Figure 7. Knee joint angle vs. time: collected data and a regression curve.

Figure 8 shows the hip-knee cyclogram obtained for a normal walk at a speed of 5 km/hr. We have marked several gait events in the diagram, the curve of which is best read counter-clockwise. Notice the good matching between our diagram and the one shown in Figure 2, coming from the research literature.⁵

Figure 9 shows the graph of the raw EMG signal of the gastrocnemius, recorded for walking at a speed of 2.5 km/hr. The EMG signal is clearly periodic, which indicates that the recording was successful. Scrubbing, when the scan mode in Coach is on, reveals that maxima and minima are consistently linked to certain gait events.

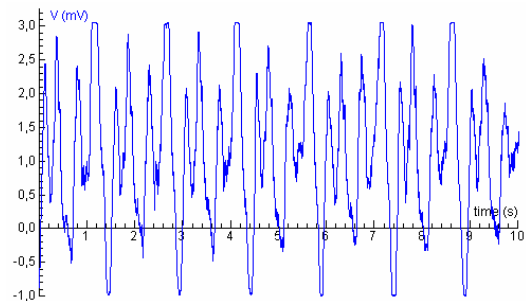


Figure 9. Recorded raw EMG signal of the gastrocnemius for a normal walk at low speed.

Figure 10 shows the graph of the processed EMG signal during one gait cycle. We have marked some gait events, which have been found by scanning the graph while watching the corresponding video frames.

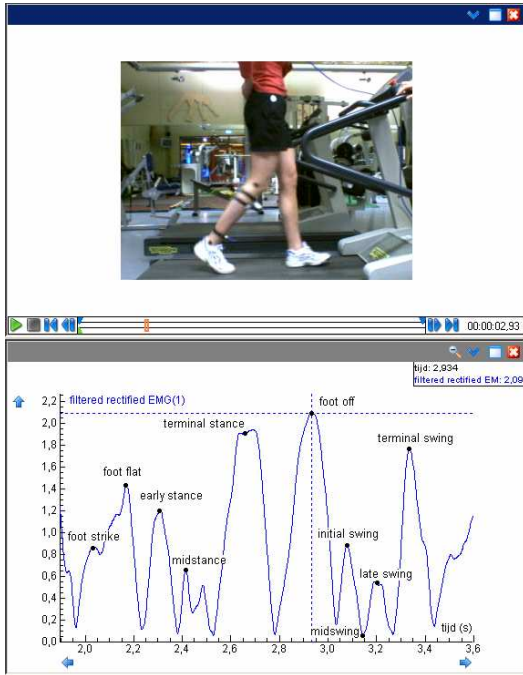


Figure 10. Processed EMG signal of the gastrocnemius for normal walking at low speed.

This diagram can be interpreted as follows: activity of the gastrocnemius is mostly during stance phase as in agreement with the on-off diagram shown in Figure 3. Peak values are at terminal stance and when the foot is taken off the ground. This can be understood because during this part of the stride, the muscle first undergoes eccentric contraction, which controls the forward movement of the tibia over the fixed foot; hereafter the gastrocnemius undergoes a concentric contraction which initiates plantar flexion, which begins the toe-off phase. At terminal swing, the muscle might be used during foot descent in order to provide stability to the ankle joint in preparation for foot contact. Beginning at foot strike and ending at midstance, the gastrocnemius is probably used for shock absorption, stability and progression of the limb.

Conclusion

The practical investigation work discussed in this paper is an illustrative example of how students can collect both qualitative and quantitative real-time data of human gait by means

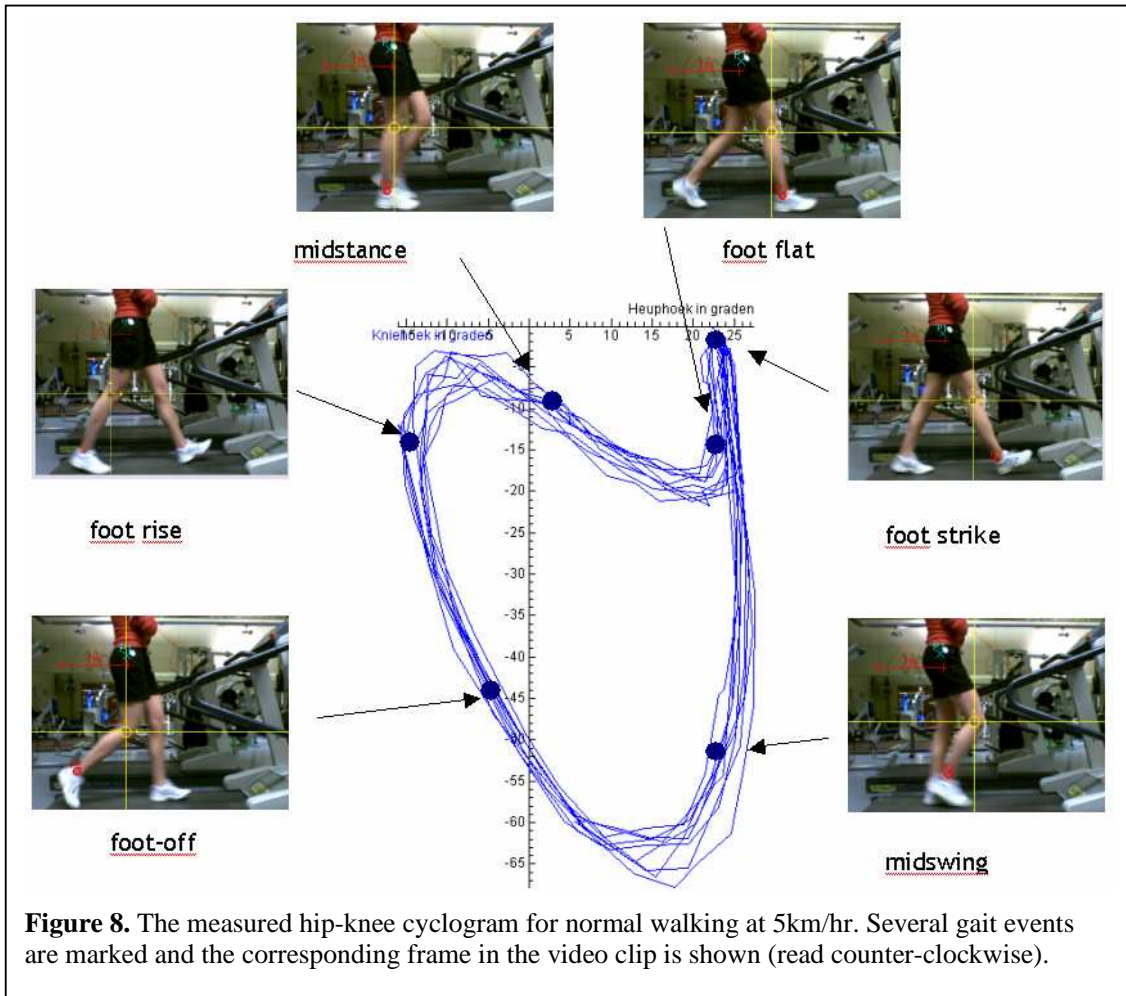


Figure 8. The measured hip-knee cyclogram for normal walking at 5km/hr. Several gait events are marked and the corresponding frame in the video clip is shown (read counter-clockwise).

of an inexpensive digital camera. Using a rather simple EMG set, they can simultaneously capture a motion on video and record muscle activity. Processing and interpreting an EMG for a muscle or muscle group is not easy. But, from the EMG signal, students can read off when muscle activity is on and off. They can often interpret the EMG signal in terms of phases and events in the gait cycle, simply by reasoning about what muscle groups are involved in producing a particular body part movement.

Conclusion

The practical investigation work discussed in this paper is an illustrative example of how students can collect both qualitative and quantitative real-time data of human gait by means of an inexpensive digital camera. Using a rather simple EMG set, they can simultaneously capture a motion on video and record muscle activity. Processing and interpreting an EMG for a muscle or muscle group is not easy. But, from the EMG signal, students can read off when muscle activity is on and off. They can often interpret the EMG signal in terms of phases and events in the gait cycle, simply by reasoning about what muscle groups are involved in producing a particular body part movement.

Motion analysis turns out to be much easier. Hip-knee cyclograms that match the ones found in the literature can easily be obtained. For many a gait pattern, the recorded hip and knee data can be successfully modeled by a force-driven, harmonic oscillator. This implies for instance that the knee joint angle during normal walk can be well described by a sum of two sinusoids.

This research project of a high school student illustrates that affordable ICT can bring students into contact with the field of gait analysis. In the project described, focus was on the leg motion during normal walk and running. But other aspects such as arm motion and other gait patterns could be investigated as well. Animal locomotion, motion of the lower limbs during (power)cycling, and sports motions are research topics that could be studied in a similar way. The authenticity of the student activities is realized by the opportunity for high school students to investigate a real-world motion in much the same way as movement scientists would do. Student can learn how physics, mathematics, and biology come together in such work.

Acknowledgments

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André Heck earned MSc degrees in mathematics and chemistry. He is project manager at the Faculty of Science of the University of Amsterdam. His research area is the application of ICT in mathematics and science education.



Caroline van Dongen was grade 12 student at the St. Antoniuscollege in Gouda when she carried out the gait investigation as her research project. She graduated in 2007 and started a study in medicine.