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TeleHeart

Using telemetry to teach about the function and control of the human heart — from face-to-face to distance education

Introduction

The way we teach physiology has been and is still undergoing major changes. There is an obvious need to provide a more integrated education that gives students the capacity to confront and solve problems. In our view, this calls for efficient use of laboratory exercises that can be used to contrast and integrate the theoretical knowledge of different physiological concepts. Despite their potential to promote a better understanding of physiology, practical laboratory exercises using animal models are questioned more and more by the students themselves and also by animal rights organisations. Over the last few years many alternatives to the use of animal models in teaching have been developed, such as computer-based simulations, video recordings or films. There are also organisations such as [InterNiche](#) that specialise in helping teachers and students to find alternatives to animal models in teaching.

One alternative to the use of animals is the study of the physiological processes occurring in the students themselves, provided that such exercises are safe. During the last decade this type of student laboratory exercise has been developed, tested and evaluated in the biology curriculum of the Department of Zoology at the University of Göteborg. Today we use a number of student-based laboratory exercises together with different commercial computer-based simulations (*NeuroSim*, *SimNerve*, *SimHeart*, *SimMuscle* and *SimBiosis*).

Besides the ethics of using animal models in teaching there are other factors that affect the design of modern laboratory exercises. The increasing interest in problem-based learning and distance education challenge the traditional concepts of practical laboratory exercises. One of the ideas with distance education is freedom in space and time, which allows the students to study when *they* have time and also at home or in locations other than university facilities. This is not always compatible with the laboratory exercises that normally form part of the curriculum and that are, in the traditional face-to-face teaching situation, done in larger groups at specific times and places. In problem-based learning, students work with specific problems and the traditional laboratory exercises do not always fit in.

Two years ago we started a project to develop a new and more flexible laboratory exercise that could be used in more than traditional face-to-face teaching contexts. In this paper we describe this new laboratory exercise (which we have called ‘*TeleHeart*’) and we also present results and student evaluations. This new system is replacing an old practical

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activity where standard electrocardiogram (ECG) equipment was used to record the ECG from both humans (students) and frogs. The new system is based on telemetry technology (that is, radio-transmitted data), which allows more flexibility since the subject does not have to be physically linked to the recording unit. The equipment is also less expensive than standard ECG recording equipment. An important concern during the development of the system was user friendliness. Considering the students' evaluations (see below) it seems that we, at least partly, reached this goal. Since it is easy-to-use, relatively inexpensive and gives students freedom to move around, the system is versatile and has been used in different settings where the conventional laboratory approach is not suitable. We have so far used *TeleHeart* in: traditional face-to-face teaching; distance education; and 'in the field' (the local amusement park). In each case, we report actual results, experimental protocols and discuss the opinions of students after the activity.

Introduction to the physiology of the heart and the cardiovascular system

The cardiovascular system

The role of the circulatory system is to supply the body with oxygen, nutrients and hormones and to transport away carbon dioxide and other waste products. It is also relevant in thermoregulation because heat from the deeper parts of the body is transported to the skin where it is dissipated. To ensure an adequate supply of oxygen and nutrients to the various organs and tissues, cardiac output (the amount of blood pumped by the left ventricle of the heart) needs to match the demand of these different organs.

The flow of blood through the cardiovascular system depends on the pressure difference between the arterial and venous side. Since the pressure in the venous side of the circulation is usually low, the driving pressure for the circulation of blood is approximately equal to the arterial pressure. Thus, to ensure an appropriate perfusion of the organism, it is important to finely regulate arterial pressure; this is achieved by monitoring blood pressure on the arterial side of the circulation. The pressure-sensitive areas are called *baroreceptors* (Figure 1).

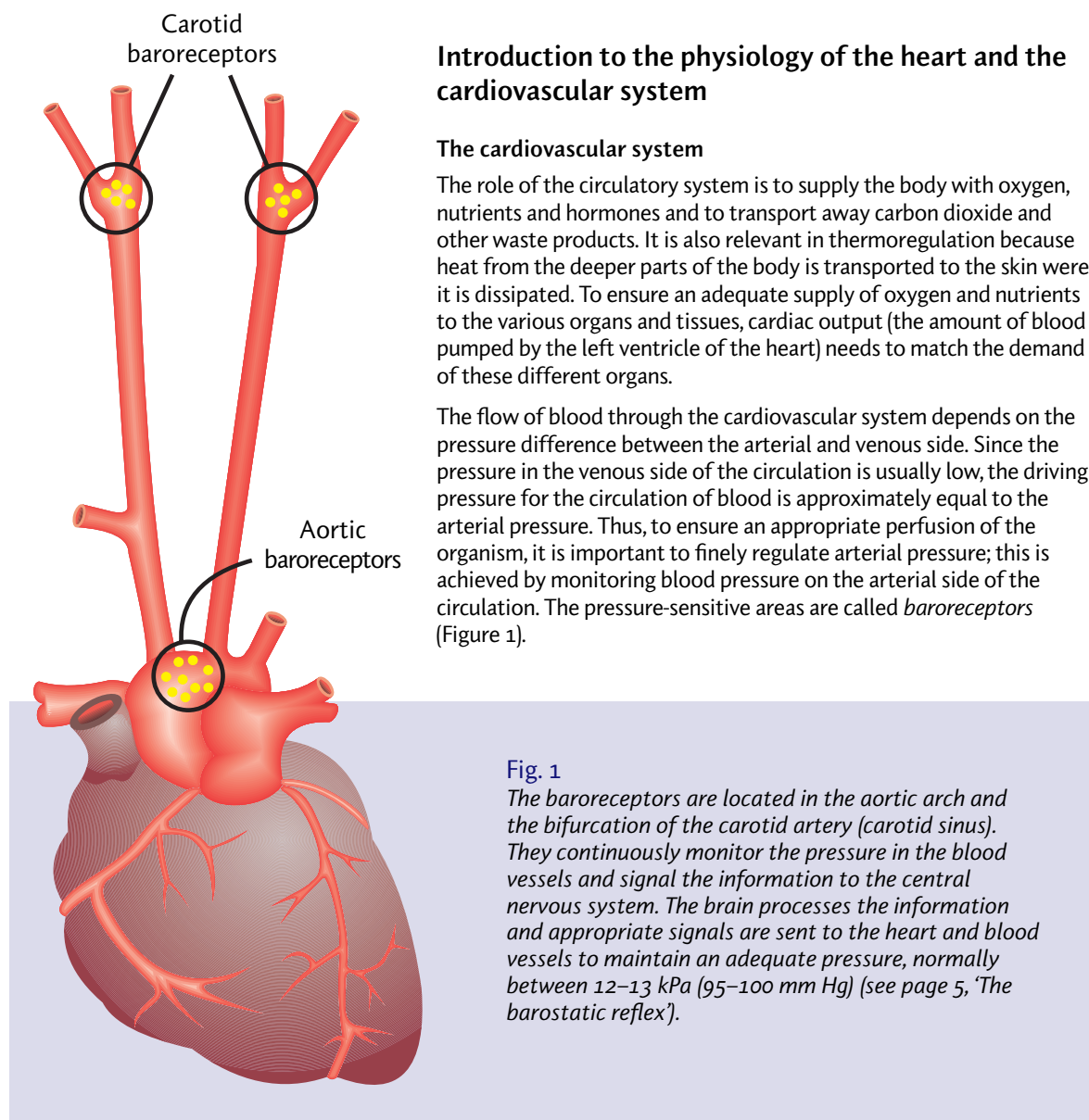
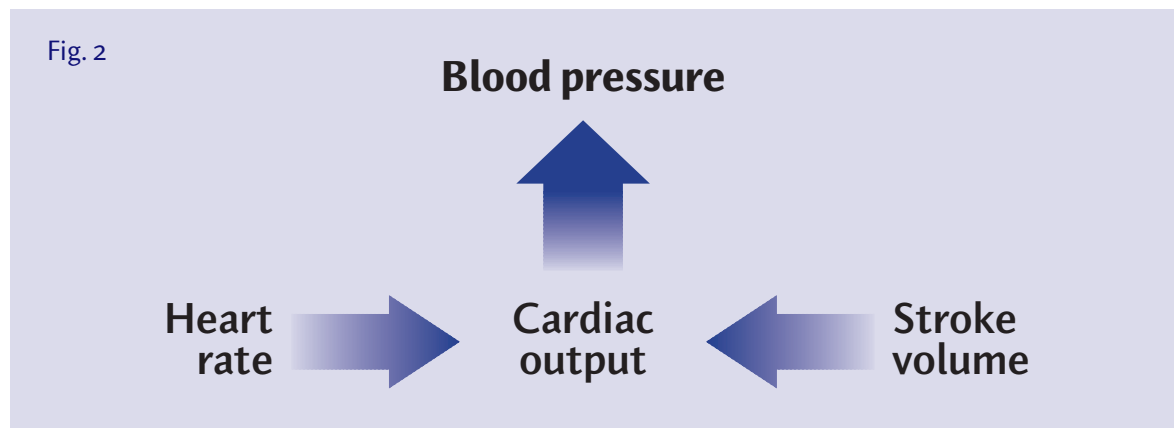


Fig. 1
The baroreceptors are located in the aortic arch and the bifurcation of the carotid artery (carotid sinus). They continuously monitor the pressure in the blood vessels and signal the information to the central nervous system. The brain processes the information and appropriate signals are sent to the heart and blood vessels to maintain an adequate pressure, normally between 12–13 kPa (95–100 mm Hg) (see page 5, 'The barostatic reflex').



As can be seen from Figure 2, cardiac output is a function of both heart rate and stroke volume. The cardiac output affects the blood pressure. Cardiac output, stroke volume and blood pressure are difficult to measure non-invasively (especially continuously). In contrast, heart rate can be measured relatively easily and non-invasively by recording an electrocardiogram (ECG), which is the weak electrical signal generated by the cardiac muscle.

The control of the cardiovascular system is complex and involves mechanisms for control of the vasculature, the heart and blood volume. The regulation of the heart itself involves changes in heart rate (chronotropic changes) and stroke volume (inotropic changes). Heart rate, which is the focus of this lab exercise can be modified by:

1. **Direct innervation.** The heart is innervated by both adrenergic and cholinergic nerves that act antagonistically. The adrenergic and cholinergic nerves are active at the same time, producing a push-pull regulation of the heart rate. This means that to increase the heart rate the activity of the cholinergic nerves are decreased while the activity of the adrenergic nerves are increased and vice versa.
2. **Circulating hormones.** The heart is also affected by circulating hormones such as adrenaline and noradrenaline, that are released from the interrenal tissue (adrenal medulla in mammals) during stress and heavy exercise.

By looking at heart rate changes caused by different types of stimuli the students can learn more about the control of the heart and couple this to their theoretical knowledge about the changes in cardiac output, stroke volume and the vasculature associated with the different stimuli.

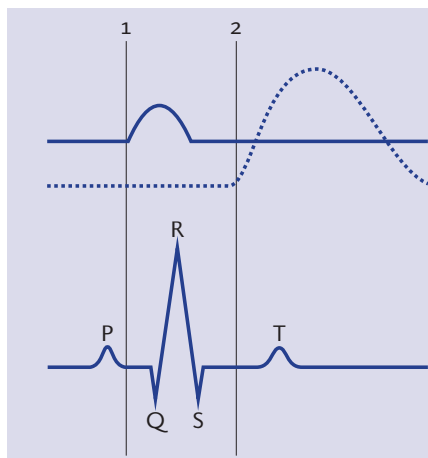
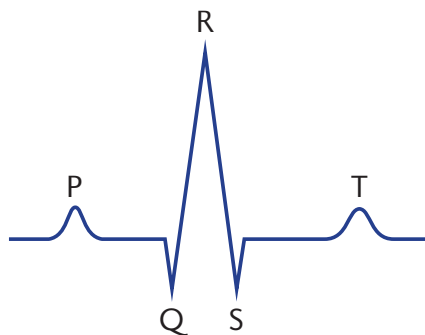
ECG — The electrical activity of the heart

To ensure an adequate function of the heart all the muscle cells that form the heart have to work in synchrony. This is possible because the muscle cells in the heart are electrically connected via low resistance connections between the cells. A pacemaker region initialise the heart beat by depolarising (change of the cell membrane voltage) the muscle cells leading to the subsequent contraction. This pacemaker region, known as the sino-atrial node (S-A node) is located in the right atrium. The pacemaker cells have a non-stable resting potential and can thus spontaneously initiate an action potential (depolarisation). At the junction between the atria and the ventricles the depolarisation is picked up by a second node called the atrio-ventricular node (A-V node), which is connected to the ventricle *via* specialised conduction

Fig. 3
Willem Einthoven undertakes an early electrocardiogram.



Fig. 4
A typical electrocardiogram (ECG).



pathways. The depolarisation spreads along these pathways down through the ventricles, ensuring that the ventricle are depolarised after the atria and that the depolarisations reach the various regions of the ventricle at the right time. The result is a muscle contraction that will force the blood out from the heart into the aorta and lung arteries.

The simplest way to measure heart rate is to feel the pulsation of one of the large arteries (the carotid artery in the neck, the femoral artery in the leg or radial artery in the wrist) and count the number of pulses (usually over 15 or 30 seconds). This method is fast and easy but it is impossible to get continuous measurements of the rate and it will only give information about the average heart rate (every 15 or 30 seconds). To obtain more detailed information about the heart rate and changes induced by different stimuli it is necessary to monitor beat-to-beat changes continuously over time. This can be done by placing electrodes on the surface of the body and recording the ECG. In 1902, Willem Einthoven was the first to record an ECG from a human and for this he received the Nobel Prize in Physiology or Medicine in 1924. Initially the ECG was cumbersome to obtain (Figure 3).

The method of recording and analysing the ECG have been refined and today the ECG is widely-used to study both the normal function of the heart and pathological changes (diseases of the heart).

It is important to remember that there is a clear distinction between the ECG (which is the electrical activation of the heart) and its mechanical action (which is the pumping of blood). The ECG describes the electrical changes induced in the heart muscle when the S-A node is depolarised and this depolarisation spreads throughout the heart. It is this electrical activity that can be picked up using a couple of electrodes attached to the body. Figure 4 shows a typical ECG. Keep in mind that the ECG is the sum of all electrical activity in the heart muscle, not the depolarisation of individual heart muscle cells.

The first peak in an ECG is called the P-wave and it represents the depolarisation of the muscle cells in the atria. The QRS complex represents the depolarisation of the muscle cells in the ventricles. To be able to beat again, the cardiac tissue needs to be repolarised and that is seen by the last peak, the T-wave, which corresponds to the repolarisation of the ventricles. The repolarisation of the atria cannot be seen since it is 'hidden' in the QRS complex. The difference in amplitude between the P and QRS peaks is due to the large difference in muscle mass between the atria and the ventricles.

Fig. 5
The upper graph is a mechanogram, describing the mechanical pumping action of the heart. The solid line indicates the activity of the atria; the dotted line shows the action of the ventricles.

The lower graph is an ECG, depicting electrical activity of the heart. Note the time difference between the depolarisation of the atria (P-peak) and the start of the contraction of the atria (labelled 1). The same is true for the ventricles where the depolarisation of the two ventricles (QRS) precedes the start of the contraction of the ventricle (labelled 2).

Fig. 6
The effect of gravity on blood pooling.

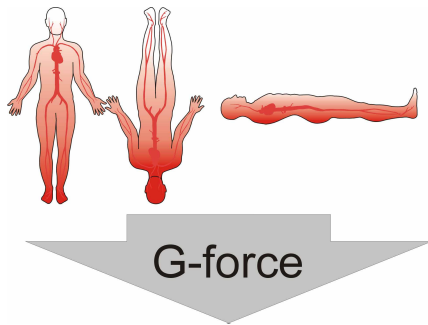


Fig. 7
Cardiac output at rest and during exercise. Percentages show the proportion of the output required by the muscles.

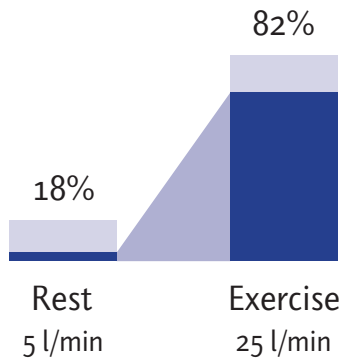
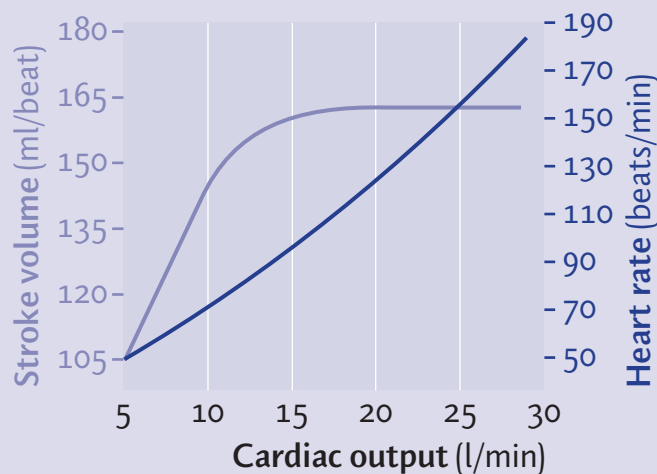


Fig. 8
Cardiac output is a function of the heart rate and the stroke volume.



The barostatic reflex

There are several different ways in which blood pressure is regulated but the by far most rapid regulation is the so-called *barostatic reflex* that adjusts the pressure on a beat-to-beat basis. If the blood pressure in the aorta and carotid arteries increases, the response from the central nervous system is to slow down the heart to reduce cardiac output. Together with other adjustments, this will restore the arterial pressure.

When standing, gravitational forces tend to pool the blood in the lower parts of the body. Figure 6 shows the effect of gravity on the blood in a person standing up, standing on his head and lying down. Going from lying down to standing up will cause the blood pressure in the head region to drop due to the gravitational force on the blood. If this is not compensated for, the person risks fainting since there will be not enough blood pressure to pump blood up to the brain. This type of rapid change in pressure is corrected by the barostatic reflex.

Physical exercise and mental stress

During exercise the active muscles increase their demand for oxygen and nutrients and to support them cardiac output is increased. In Figure 7 the left bar represents cardiac output at rest, which is around 5 litres per minute. At rest, the demand from the muscles is low and only around 18% of cardiac output is used to supply the muscles. During exercise, however, cardiac output can increase up to 25 litres per minute (right bar in Figure 7). This is mostly due to a massive increase in blood flow through the active muscle groups, which may account for up over 80% of cardiac output. The increase in cardiac output is a function of an increase in both heart rate and stroke volume (Figure 8).

Heart rate is also affected by emotional changes such as stress and excitement. In this case it is not a blood pressure change or an increased demand from active muscles that induces the change in the heart rate, but instead this is regulated *via* the central nervous system and circulating hormones such as adrenaline and noradrenaline.

TeleHeart — a telemetric ECG system



Fig. 9

Electrode placement

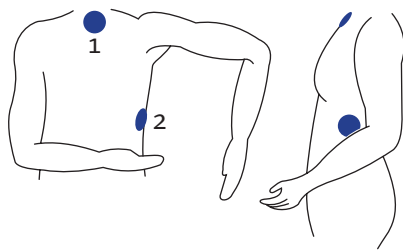
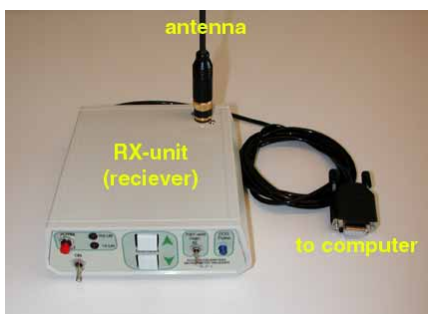


Fig. 10



Fig. 11



The system and laboratory exercise that is described below can be used in traditional face-to-face teaching but we have also tested and used it in problem-based learning and distance education. It is user-friendly and relatively inexpensive. It consists of an ECG amplifier that is carried by the subject; the signal(s) is/are transmitted to a receiver that in turn is connected to a personal computer. Custom-written software is used to acquire the signal and calculate the heart rate on-line. The data can be stored on disk for further processing after the experiments.

The equipment (except the computer that is needed) is packed in sturdy cases (left) that can be send by ordinary mail to students in a distance education situation or handled by the students themselves in a problem-based learning situation.

Description of telemetric equipment

A normal clinical ECG recording depends on at least 3 electrodes and usually 7 electrodes are used to obtain detailed information from the heart. Our ECG biotelemetry system is based on a two-electrode design (Figure 9), which makes the system simpler to use.

The ECG/G-force biotelemetry system consists of an ECG/G-force biotelemetry transmitter unit (TX-unit, Figure 10 — shown here without the G-force sensor) and a receiver unit (RX-unit, Figure 11).

The TX unit amplifies the ECG signal from the heart picked up by the two electrodes that have been placed on the body as shown in the figure to the right. If G-forces are of interest a small G-force unit can be connected to the TX unit. The signal(s) is then transmitter to the RX unit. The ECG signal is analysed and a special circuit produces a pulse each time it detects the R-wave part of the ECG waveform (see description of the ECG in the introduction). This special heart rate circuit obtains the pulses relating to R-waves based on slew rate, instead on amplitude threshold as used by many other designs. This reduces the false R-wave indications in the presence of noise caused by motion artefacts. It is possible to compensate for differences in the amplitudes of the ECG from different subjects by changing the amplification. The output from the RX unit consists of the raw ECG signal, the pulse for each R-wave and the X- and Y-axis G-forces. If only heart rate is of interest the 'pulse signal' is fed into the serial or parallel port of the computer running the *TeleHeart* software (see below for brief description). The program plots the beat-to-beat heart rate on the screen. In this setup the program uses only the standard serial or parallel port of the computer and no extra hardware is needed. To be able to see the raw ECG-signal or to record the G-forces an analogue-to-digital converter (A-D converter) is needed.

The system has a range of at least 150 m in an open environment. Obstacles such as metal structures, large trees, houses, *etc* will limit the range to various degrees depending on the severity of obstruction.

The *TeleHeart* software

One of our main goals during the development of the software was ease-of-use. We wanted a system (both hardware and software) that could be used by the students without any lengthy instructions.

Once the software is installed on the computer (self-installing from CD) and started there are four options:

1 Acquire ECG

This subprogram will use an A–D converter to acquire the raw ECG signal from the RX unit and present it on the screen. The data can be saved to disk for further analysis. This subprogram is useful for looking at the quality of the signal and making fine adjustments of the RX and TX units to optimise the signal before the experiment. If only the ECG signal is of interest (not the G-forces) an AD42 single channel A–D converter from PICO Technology Limited that communicates with the computer *via* the parallel port can be used. If G-forces are to be recorded a National Instrument A–D converter is used to obtain both the ECG and the X- and Y-axis G-forces.

2 Acquire Heart rate

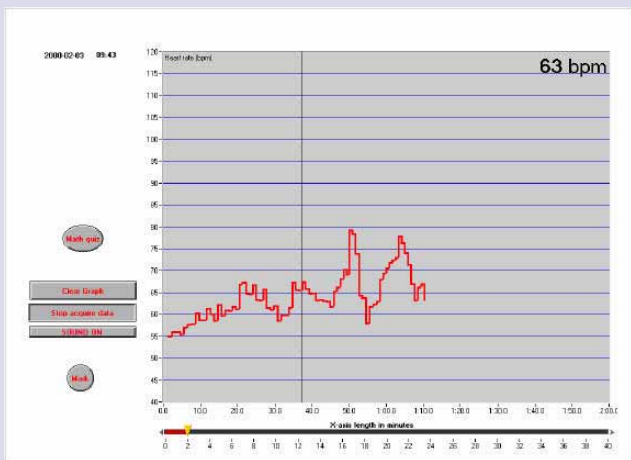
This is done using the pulse-output from the RX unit via the serial port (or parallel port) of the computer. This is the “standard” module of the software, which plots beat-to-beat heart rate on the screen (see figure to the right). The data can be stored to disk and it is possible to insert marks in the records to help during the analysis afterwards. Since the ECG signal do not differ from the electrical signals generated by other muscle groups the system will pick up also these signals, leading to artifacts in the heart rate trace. The software has an inbuilt correction for this and further ‘cleaning’ of the data can be made offline.

3 Acquire both the raw ECG signal and heart rate

This is essentially point 1 and 2 together. It can be useful to make a rapid test of the quality of the signal during an experiment

4 Plot data

This subprogram will plot data that was previously stored. Simple calculations can be performed on the data, using cursors to mark regions of interest.



Hardware requirements

- PC with a Pentium processor
- Monitor with 1024 x 768 resolution
- One free serial or parallel port (COM1, COM2 or LPT1)
- Optional A–D converter (for the raw ECG and G-force signals)

Left: A screenshot of the *TeleHeart* software in use.

Experimental protocol and results for *TeleHeart* in face-to-face and distance education teaching

We have used several different protocols for *TeleHeart* based on the type of teaching situation. Below is an example of a set of tasks that we have used both in traditional face-to-face teaching and in distance education. The protocol is handed out to the students, or in a distance education situation it is supplied to the student with the equipment. The students become acquainted with equipment either helped by a tutor in the traditional teaching situation or *via* a detailed manual in distance education. They follow the protocol and answer the questions and generate the figures that will be used in a written report. The results are then discussed and put into context with the rest of the control mechanisms involved in the cardiovascular system.

Specimen student instructions

1 Resting heart rate

Start acquiring data by clicking on the **Acquire data** button and acquire data for at least 15 minutes while lying down and relaxing as much as possible (without falling asleep!). Save the data by clicking on the **Stop acquire data** button.

Questions and tasks

- What is the average heart rate during the last 5 minutes?
- What are the lowest and highest heart rates during the last 5 minutes?
- Create a JPG file of the last 5 minutes.

2 Orthostatic reaction — barostatic reflexes

With this exercise you may need help or at least place yourself so you can lie down and still operate your computer (that is, see the screen and use the mouse). Lie down and relax for at least 10 minutes. Then start acquiring data by clicking on the **Acquire data** button and acquire data for at least 5 minutes (if you are alone you can start acquiring data immediately and lie down for 10 minutes). Then, stand up quickly and remain standing while continuing to record heart rate for another 2–3 minutes before you save the data by clicking on the **Stop acquire data** button.

Questions and tasks

- What is the average heart rate when the test person is lying down?
- What is the lowest and highest heart rate when the test person is lying down?
- What is the highest heart rate when the test person stands up?
- What are the lowest and highest heart rates when the test person is standing?
- Create a JPG file showing the change in heart rate during this test.

3 Heart rate changes during mental work

Start acquiring data by clicking on the **Acquire data** button and acquire data for at least 5 minutes while sitting quietly in a chair. Then start the mathematical test by clicking on the **Math quiz** button. You have 2 minutes to answer as many questions as you can — try to get at least 25 correct answers. Each question has a 5-second time limit and if you do not answer within these 5 seconds the question will be considered as though you had answered wrongly. The next question will then be presented to you. Save the data by clicking on the **Stop acquire data** button.

Questions and tasks

- What is the average heart rate before the test person starts the questions?
- What are the lowest and highest heart rates during the last 2 minutes before the test?
- What is the average heart rate (over 30 seconds) at the end of the test?
- What are the lowest and highest heart rates during the test?
- Create a JPG file of the entire test (from 3 minutes before the test starts until the end of the test).

4 Heart rate changes during exercise — Step test

A simple way to show the effect of exercise on heart rate is to do a step test. Depending on your own height, you need to find something that is between 25 to 50 cm high that you can step onto; for example, a small chair or a couple of books. Start acquiring data by clicking on the **Acquire data button** and acquire data for at least 5 minutes before you start the step test, standing still in front of whatever you selected to step on. Continue to record heart rate and start the step test by doing 10 step-ups at a rhythm of 1 step-up every 2 seconds. Rest until the heart rate has returned to the resting level (that is, the heart rate before the first step-up test). Save the data by clicking on the **Stop acquire data** button. Then repeat the test with an increasing number of step-ups for each step test (20, 30 and 40).

Questions and tasks

- What is the average heart rate before the test person starts the exercise?
- What is the lowest and highest heart rate during the last 2 minutes before the first step-up test?
- What is the average heart rate (over 30 seconds) at the end of each step-up test?
- What are the lowest and highest heart rates during each step-up test?
- Create a JPG file of each step-up test.

5 The diving reflex

Arrange two chairs so that they are facing each other. Put a bucket or other container filled with cold water on one of the chairs. Start acquiring data by clicking on the **Acquire data** button and acquire data for at least 3–5 minutes sitting on the chair facing the other chair with the water bucket. Then immerse your face in the water and hold it in the water for 30 seconds. Save the data by clicking on the **Stop acquire data** button. Make sure that you do not splash water over the transmitter or receiver!

Questions and tasks

- What is the average heart rate of the test person when sitting on the chair?
- What are the lowest and highest heart rates of the test person while he/she is sitting down?
- What is the lowest heart rate when the test person immerses his or her face in the water?
- Create a JPG file showing the change in heart rate during this test.

Results

1 Resting heart rate

The first task was to record heart rate at rest without any additional stimuli. Figure 12 represents such a recording from a student (heart rate on the Y-axis and time on the X-axis in all graphs). Heart rate in this student ranged from 47 to around 60 beats per minute. In textbooks resting heart rate is often reported as a single value and this is also true when measuring heart rate by feeling of one of the large arteries. This is misleading since it gives information about average heart rate over a certain period at a specific age. From recordings of beat-to-beat changes it is evident that the heart rate is highly variable — this is due to push-pull regulation by the sympathetic and parasympathetic nervous system. This is important for the students to understand and they usually are surprised when they see the variability.

2 Orthostatic reaction — barostatic reflexes

In the second test, the barostatic reflex is studied. The student is lying down on a bed or table until the heart rate has stabilised and then he or she stands up. Figure 13 shows the result from such a test. Heart rate in this particular student stabilised at between 50–60 beats per minute and a dramatic, rapid increase was seen as the student stood up (indicated by the blue arrow) with a peak heart rate of close to 90. This was rapidly reversed to a lower level but heart rate in the standing position was higher than in the lying position. This exercise shows the rapid compensation for the changes in pressure associated with changes in posture. It is hard, if not impossible to pick up these rapid changes by feeling the pulse since it is so short-lasting. It is important for students to understand the fast regulation of heart rate on a beat-to-beat basis. This mechanism is very important for the fine-tuning of blood pressure and this exercise can form a basis for discussion about the mechanisms and nervous pathways behind this type of rapid regulation of the heart and vasculature.

Fig. 12
Resting heart rate.

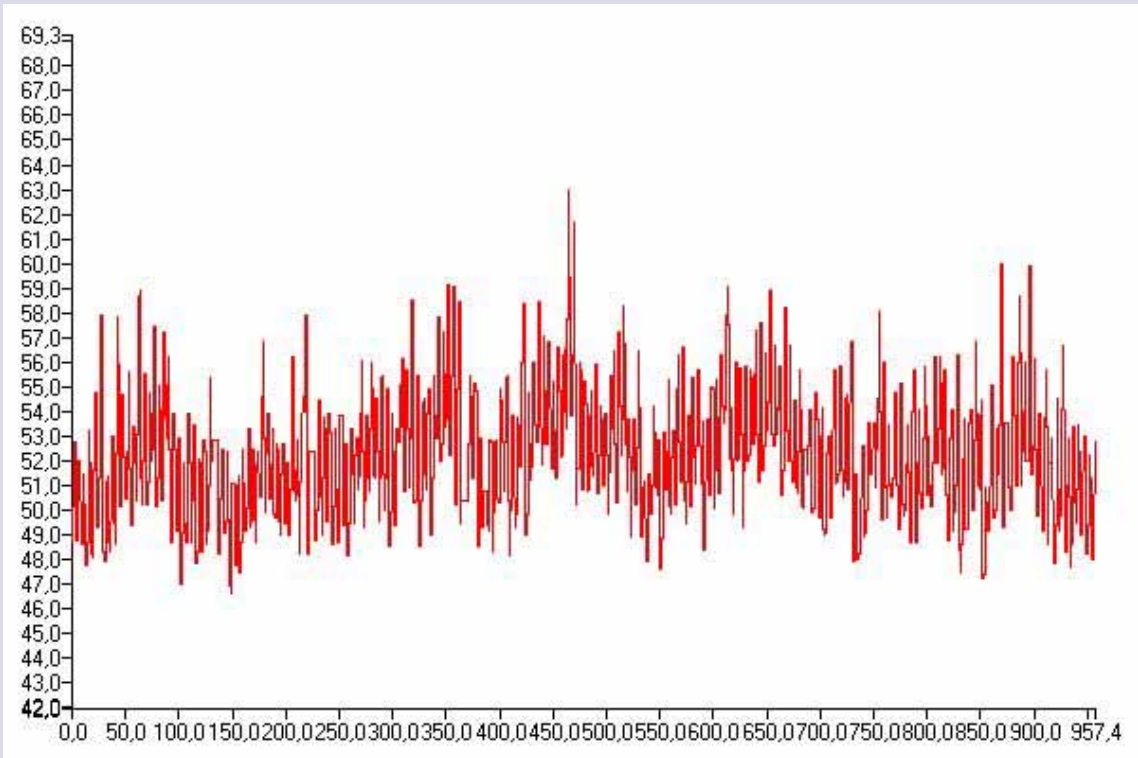
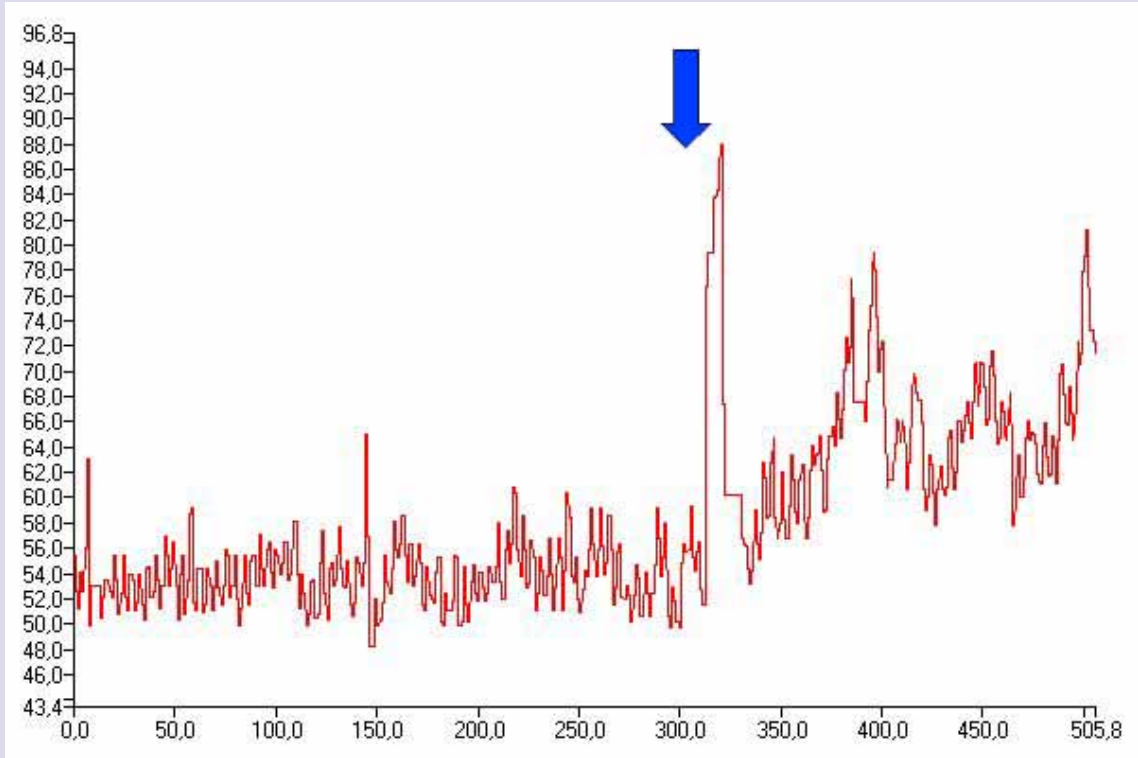


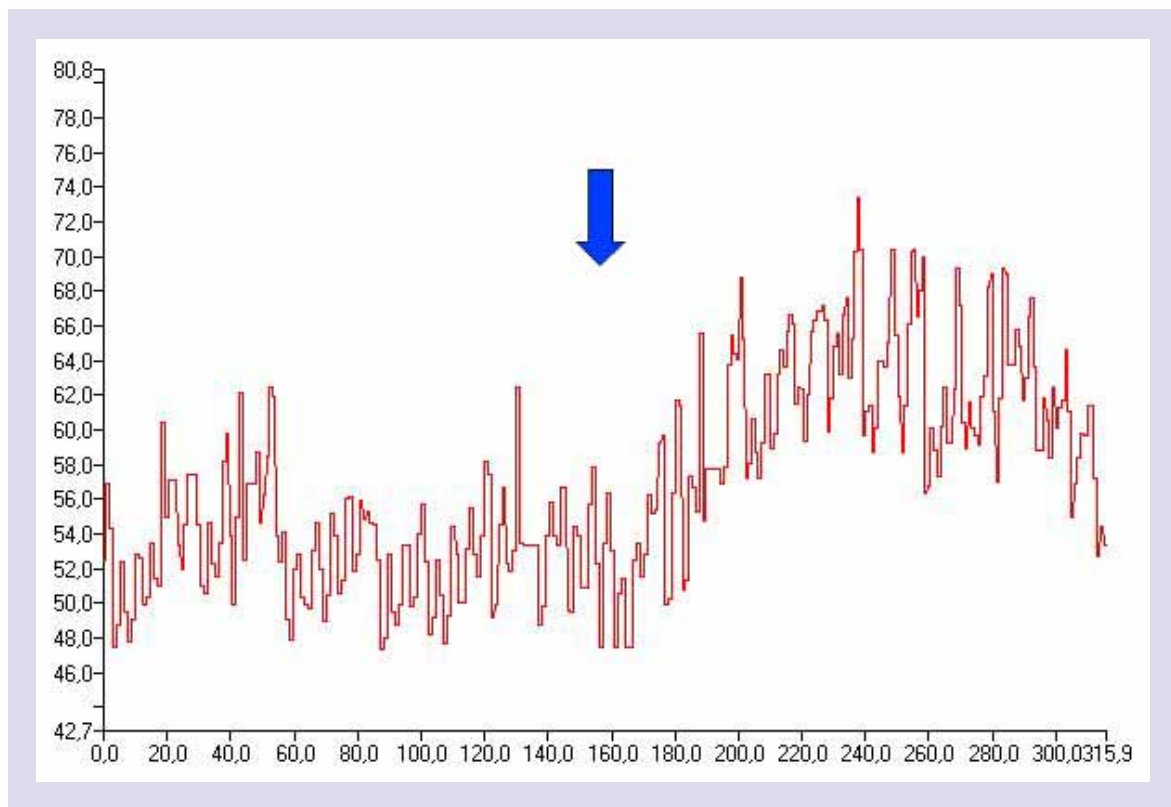
Fig. 13
Ortostatic reaction — barostatic reflexes.



3 Heart rate changes during mental work

In the third task the students were asked to study the effects of mental work. This consists of a 'maths quiz' where mathematical questions are shown on the screen and the students have 5 seconds to answer each question. Figure 14 shows a result from one of these tests. The student sits quietly in front of the computer and then starts the quiz (start of quiz indicated by blue arrow). As can be seen from the graph, heart rate is increasing during the test. This exercise leads to the question about why heart rate increases during stress even without any physical activity. It is also interesting to see the large variations between students in response to this test; some show a very large increase in heart rate while some show no response at all. It was also clear from the results coming from the distance education students that they showed less response to this test. The best responses are seen when a group of students are standing around the test subject encouraging the student showing the effects of social pressure on the stress response. This experiment can be used as an introduction to stress effects on the circulation, brain blood flow during mental work or even the use of lie detectors.

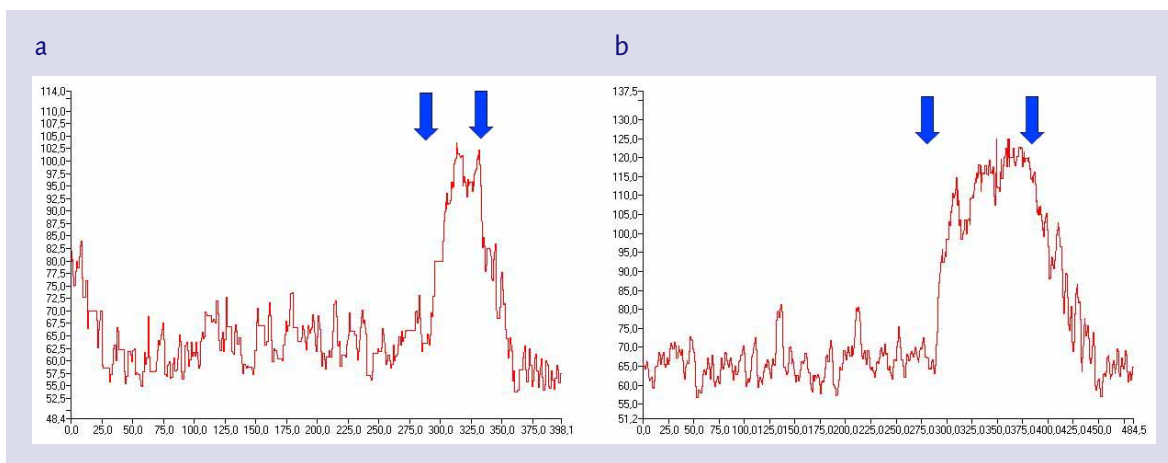
Fig. 14
Heart rate changes during mental work.



4 Heart rate changes during exercise — Step test

The fourth task tests the effects of physical exercise, either on an ergonometric bike or a simple step test, depending on the situation. The graph below shows the results of a step test send in by one of the distance education students. In this protocol the students are asked to do 10, 20, and 30 step-ups with enough time between for heart rate to return to the level before tests. Figure 15 shows that exercise increases heart rate. The first long blue arrow indicates the start of the step-up exercise while the second shorter arrow indicates the end of the exercise. These results can form a basis for discussion about the effects of physical exercise on the cardiovascular system; the duration and intensity of the exercise will be reflected in how much heart rate increases and the time taken to recover. The changes in heart rate should also be coupled to the changes in stroke volume and cardiac output.

Fig. 15
Heart rate changes during exercise.
a: after 10 step-ups.
b: after 20 step-ups.



5 The diving reflex

The final exercise in the suggested protocol is a test of the diving reflex. Figure 16 shows the result from this test. In this exercise the students are asked to immerse the face in cold water for a period of 10–20 seconds. As can be seen from the graph, heart rate falls when the face is immersed. Water temperature is relevant, since colder water shows larger changes in heart rate. This exercise can be varied by asking the students to use a snorkel that will make it possible for them to breath during the face immersion. The change in heart rate differs if the subject is allowed to breath while the face is immersed or if the subject has to hold it breath during the immersion. This type of test can be used in discussing adjustments of the cardiovascular system during diving in humans and other animals. It can also be used in the discussion about temperature receptors and their role in the adjustments of the cardiovascular system.

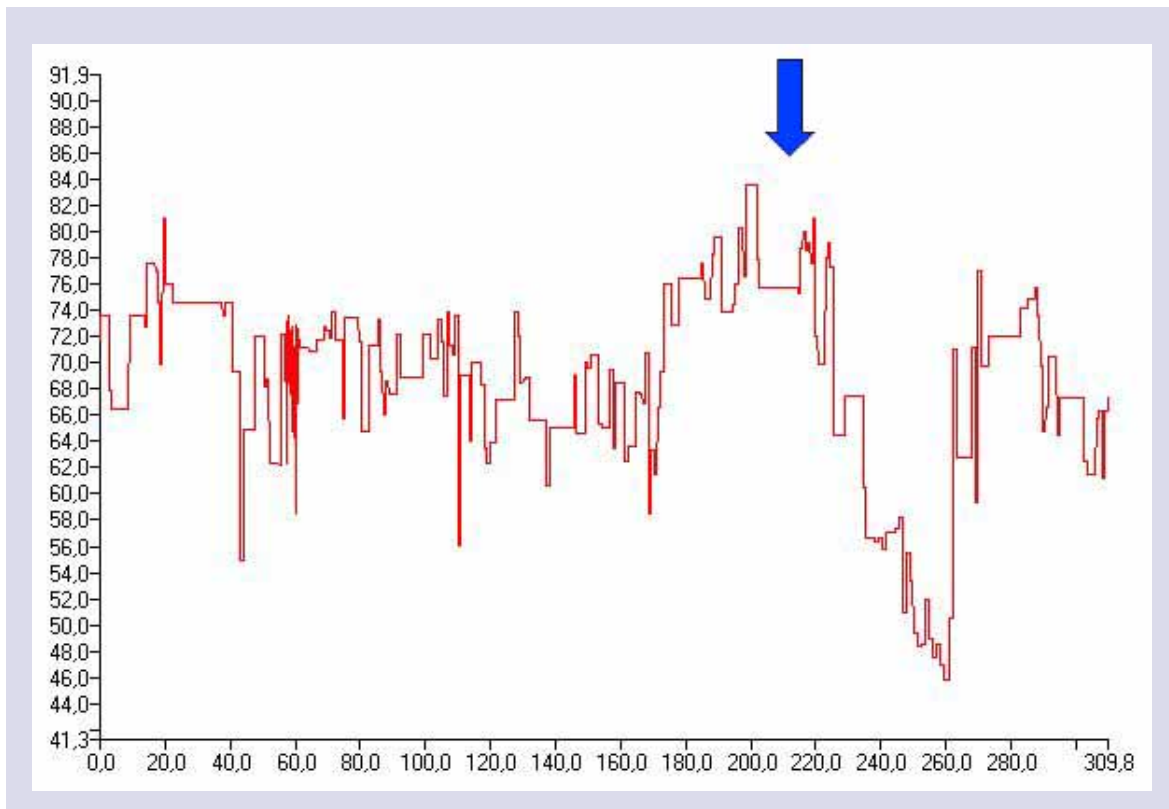


Fig. 16
The effect of the diving reflex on heart rate.

Experimental protocol and results for TeleHeart ‘in the field’

Since the system is based on radio transmission of the data (ECG and G-forces) the subject is free to move around and this makes it possible to record heart rate and G-forces from subjects that are doing normal daily activities and some not so normal activities such as going to a funfair.

Göteborg has a funfair called Liseberg that we use for our project ‘Slagkraft’. Here, together with the department of Physics, we teach physics and physiology together. The different forces that the subjects are exposed to during the rides affect the cardiovascular system and we can measure the changes in heart rate as a result of these forces. Not only the forces in the different rides but the anticipation before the ride affects the heart rate and this can also be discussed in terms of effects of stress and excitement on the cardiovascular system.

We have so far primarily been using three different rides for our ‘field’ lab exercises:

1. **‘Uppskjutet’** is a vertical tower where people are accelerated upwards with around 3G and then allowed to fall back towards the ground freely. In contrast to Aerovarvet, Uppskjutet is a very fast attraction and sometimes it is difficult to pick up the changes in heart rate due to the fall in blood pressure in the head region because of the upward acceleration.
2. **‘Höjdskräcken’**, a ride that can be described as the opposite to Uppskjutet. People are slowly raised to 60 metres above the ground and then accelerated downwards.

3. **'Aerovarvet'**, which is a large 360-degree swing that makes 6–8 full turns. It is relatively slow, especially in the upper position when people hang upside down, and this allows the body to adjust to the increased blood pressure in the head region.

Data and a short discussion of the results are presented for all three attractions below.



'Uppskjutet'

Figure 17 is a result from 'Uppskjutet'. At the red arrow the ride starts and accelerates upwards with around 3G. Heart rates before the ride starts are around 60–80 beats per minute and increase to close to 150 beats per minute at the onset of the ride. The change in heart rate is in this case most likely a mixture of excitement and a blood pressure drop due to the acceleration upwards that forces the blood into the lower part of the body and triggers the barostatic reflex.

Fig. 17
The effect of 'Uppskjutet' on heart rate.

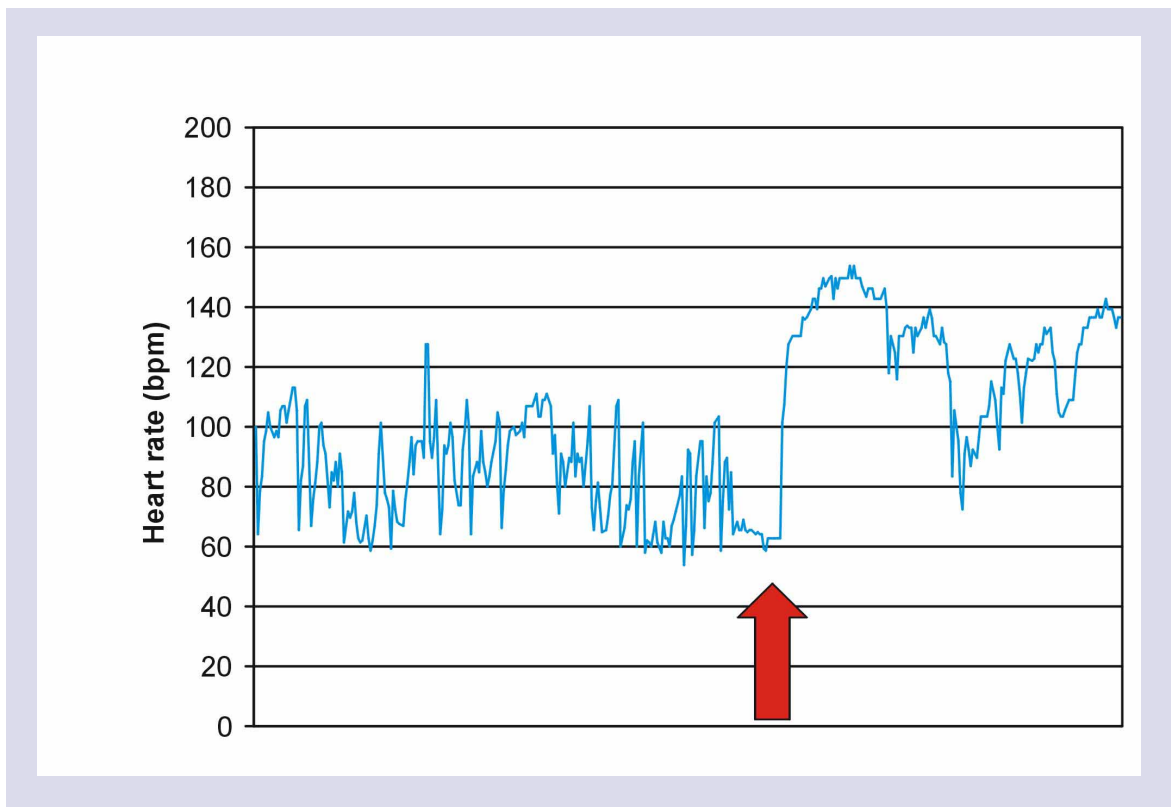
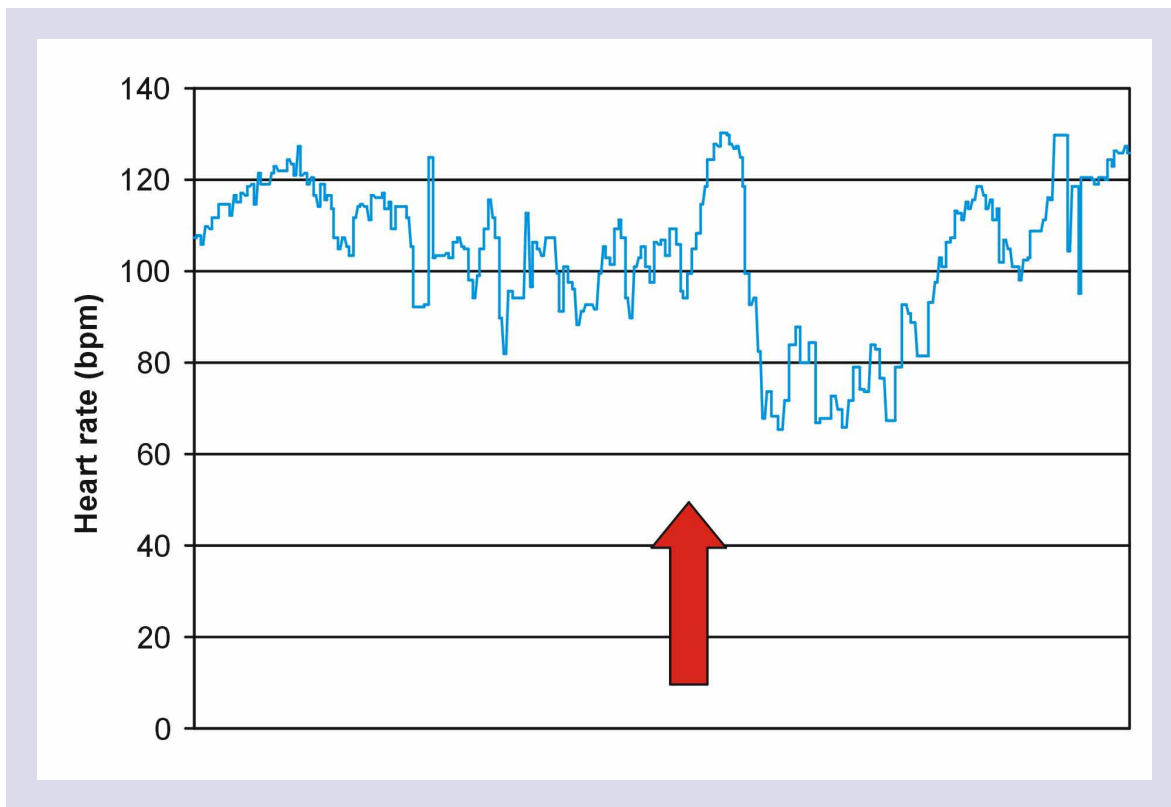




Fig. 18
The effect of 'Höjdskräcken' on heart rate.

'Höjdskräcken'

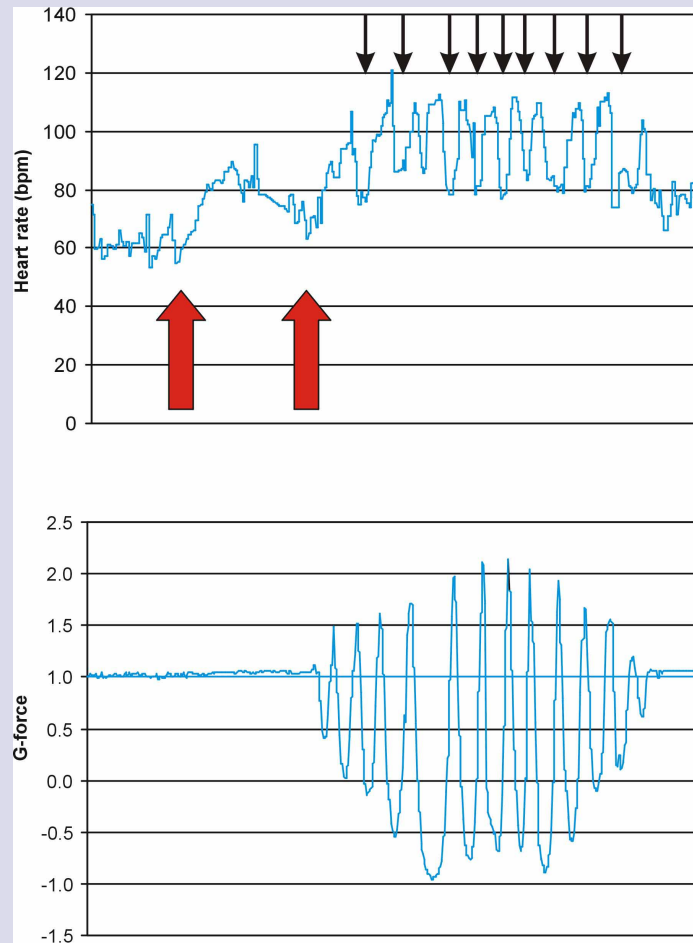
Figure 18 shows heart rate data from 'Höjdskräcken', in this case the heart rate before the ride is between 80 and 120 beats per minute. In this attraction people are slowly carried 60 meters above the ground and this may be the reason for the higher heart rate before the start of the ride (compared to 'Uppskjutet'). At the arrow the ride accelerates downwards and the response is an increase in heart rate followed by a decrease. The initial increase in heart rate is most likely to be caused by excitement while the decrease seen after this initial response is due to the blood pressure increase in the head region as a result of the downward acceleration.



'Aerovarvet'

The upper graph in Figure 19 shows heart rate data and the lower graph shows the G-forces (Y-axis) from a ride in 'Aerovarvet'. In this case, heart rates before the ride starts are around 60. When the safety restraints are closed just before the ride (first red arrow) an anticipatory increase in heart rate can be seen. As the ride starts, indicated by the second red arrow, heart rate again starts to increase due to anticipation. Every time the person hangs upside down (indicated by smaller black arrows) heart rate drops due to the increased blood pressure in the head region. At his time the G-force readings are close to $-1G$. When the swing comes to its lower position the G-force affecting the body is close to $2G$ — this will force the blood into the lower portion of the body and blood pressure in the head region will decrease with a resulting increase in heart rate. This cyclic change in heart rate can be seen for every turn of the swing.

Fig. 19
 The effect of 'Aerovarvet' on heart rate (changes in G-forces during the ride are also shown).



Suppliers

In Europe, the *TeleHeart* system may be obtained through the University of Göteborg, from which more information may also be obtained. Please contact Michael Axelsson (m.axelsson@zool.gu.se).

In the United States of America, those who are interested may contact Pitsillides Koullis Consulting, 3461 Rancho Rio Way, Sacramento, CA 95834. USA. Telephone: + 1 (916) 568 1972. eMail: koullis@jps.net

Further reading

Textbook of medical physiology by A.C. Guyton (2000) Philadelphia : Saunders (10th edition) ISBN: 0 7216 8677 X.

Circulatory physiology — the essentials by Smith, J. J. and J. P. Kampine (1990) Baltimore, Williams and Wilkins. ISBN: ????????????

Einthoven W. (1902) Galvanometrische registratie van het menschelijk electrocardiogram. In: *Herinneringsbundel Professor S. S. Rosenstein*. Leiden: Eduard Ijdo, 101–107.

The electrocardiogram in infants and children: A system approach by A. Garson (1983) Lea and Febiger, Philadelphia. ISBN: ????????

Web sites

InterNiche

<http://www.euroniche.internetworking.de/EuronicheHelp.html>

PICO Technology Limited

<http://picotech.com/> or <http://www.lanzo.se>

Liseberg

<http://www.liseberg.se>

The 'Slagkraft' project

<http://www.fy.chalmers.se/LISEBERG>