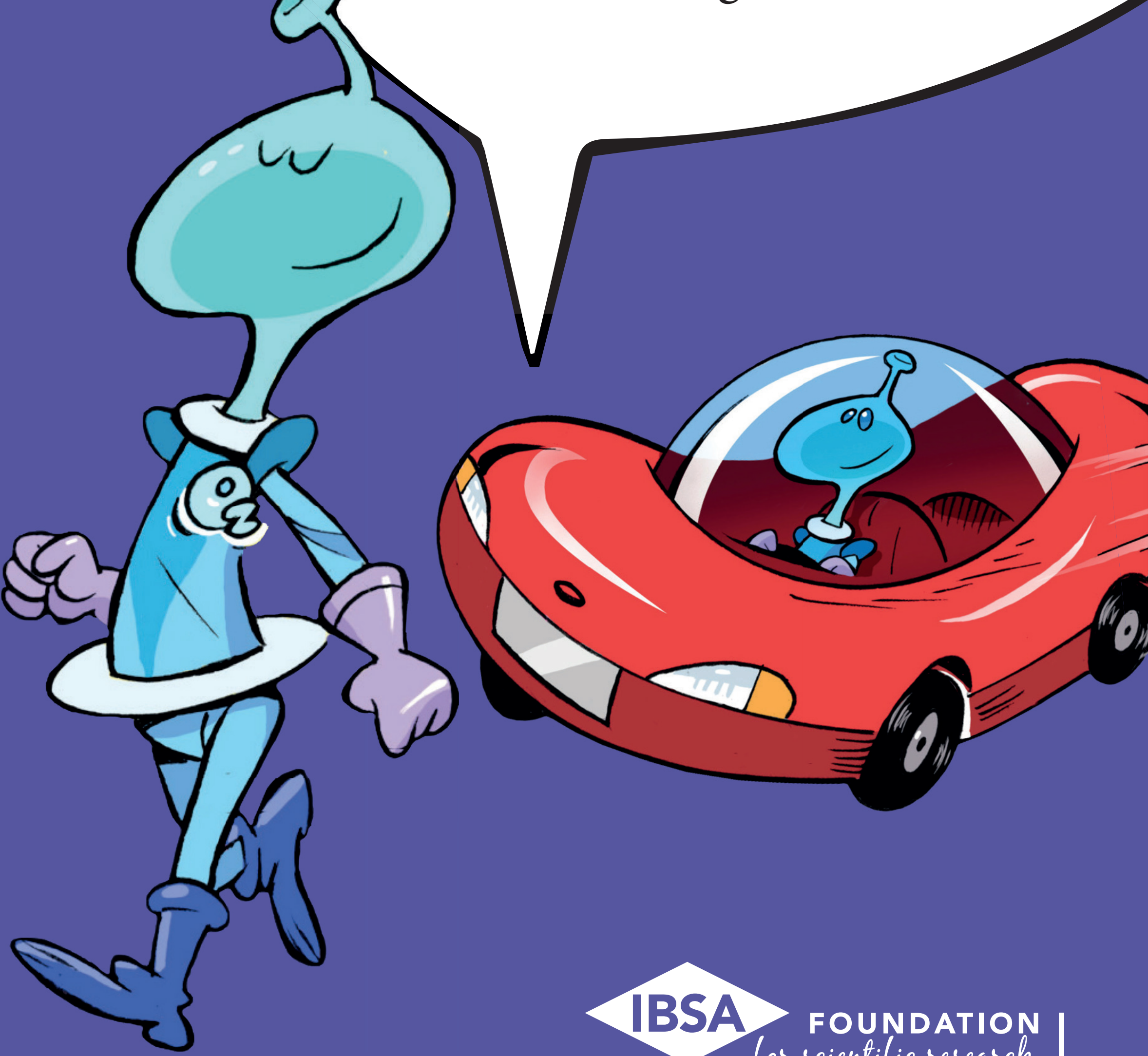
LET'S SCIENCE!

3

Giuseppe Vassalli

THE HEART AND THE BRAIN TALK TO EACH OTHER...

How the two organs interact



IBSA FOUNDATION for scientific research

LET'S SCIENCE!

Giuseppe Vassalli

THE HEART AND THE BRAIN TALK TO EACH OTHER...

How the two organs interact

IBSA FOUNDATION for scientific research

ti

Repubblica e Cantone Ticino
Dipartimento dell'educazione, della cultura e dello sport

Original edition: *Cuore e cervello si parlano... Come i due organi interagiscono* (Carocci, 2019)

Graphic project by Ulderico Iorillo and Valentina Pochesci

CONTENTS

PREFACE

How familiar are we with the repercussions of scientific research and medical practice for our daily lives? What are the “passions” and motivations that drive researchers and healthcare professionals? What do we know about their professions?

Society strives to make science and its implications known to ordinary people in many different ways. Just think, for example, of the variety of leaflets promoting the importance of a healthy lifestyle and well-being in general. Of course, school does its part as well, introducing the principles of scientific literacy and raising awareness of a series of issues that help foster scientific thinking among young people.

These considerations are in fact the starting point for the *Let’s Science!* project, carried out by the IBSA Foundation for Scientific Research in collaboration with the Department of Education, Culture, and Sport of the Canton of Ticino (DECS). The partnership has made it possible to identify interesting topics that have been addressed by the project, getting scientists working in the canton involved. Two different worlds that are often far apart – scientific research and school – have thus been brought together, promoting dialogue between professionals and students through themed workshops, in order to develop awareness of both the topic itself and how to communicate it.

But what was the range of topics the project would address and what considerations led to certain strategic decisions? Science and research are advancing rapidly, especially in biomedicine and related disciplines, and the continuous expansion of fields of investigation requires a constant effort to stay up to date, in order to both maintain a historical perspective and accommodate the numerous innovations. Access to scientifically accurate information, conveyed in accessible language, opens up the opportunity for children to get to know and become passionate about topics that are generally considered “difficult”.

And that’s the idea behind the *Let’s Science!* series, which aims to broaden the range of scientific topics that can be explored at school. The topics, which are interdisciplinary and directly related to individual health and well-being, are presented in an innovative way: the scientific text is in fact accompanied by a story that draws on the experience of cantonal middle school classes, who, under the guidance of their teachers, developed original scripts, which were then translated into comics by professionals in the industry.

The only thing left for us to do is invite young readers to explore the fascinating fields of research presented by *Let's Science!*, which in turn open up opportunities for further questions and insights. Who knows, one of these readers might in turn one day become the one taking important steps forward in understanding the complexity of life and the delicate balance that allows us to be healthy and happy. Enjoy reading!

SILVIA MISITI
Director of the IBSA Foundation for Scientific Research

NICOLÒ OSTERWALDER
Educational consultant for science at the Department of Education (DECS)

The heart and the brain talk to each other...

PART ONE

INTRODUCTION

Since ancient times, the heart has been seen as the seat of love and the soul. The ancient Egyptians, one of the first cultures that showed a particular interest in the heart, used two distinct terms: *ib*, to designate the heart-soul, and *haty* for the heart-organ. When they mummified a body, they left the heart in the chest so that the gods could compare its weight with that of a feather, the symbol of the goddess Maat, who represented justice. If the deceased had committed evil and unjust acts in life that made their heart heavier than the feather, they would not be admitted to the kingdom of the dead. The brain, on the other hand, was removed from the body [**figure 1**].

Today, the roles have been reversed, so to speak. The brain is the organ of the mind, in a sense the center of life, and we tend to see the heart simply as a muscular pump... but it's not. The heart is actually a more complex organ. In addition to pumping blood through the circulatory system, it interacts with the brain and other organs. For its part, the brain continuously sends signals to the heart.

Figure 1 Weighing of the heart in Ancient Egypt (*Book of the Dead of Ani*, circa 1275 B.C.E.)

The autonomic nervous system plays a central role in the heart-brain connection. Its activation can stimulate both brain and heart activity. For example, when we exhale, we send signals that influence our heart rate. If our breathing rate is regular, our heart rate variability is coherent, otherwise it becomes chaotic. The latter condition occurs when the activity of the sympathetic nervous system (a system that evolution has shaped to predispose us to "fight or flight" reactions) becomes dominant, as happens in all stressful and anxiety-inducing situations.

While chaotic heart rate variability reflects a state of emotional tension, coherent variability can be restored by breathing slowly, deeply, and rhythmically. This effect can also be achieved through contemplation or meditation techniques (just consider that nowadays there are smartwatch applications that prompt us to breathe in a regular rhythm when they detect we are stressed). The most surprising aspect is that re-establishing coherent heart rate variability through controlled breathing seems sufficient to improve our emotional state. While it is well known that emotions influence the heart rate, the influence of the heart rate on emotions is a recent discovery. This discovery "closes the circle" of the heart-brain connection, which can be seen as a single operational control unit that controls our physical and emotional well-being. In this sense, the heart-organ (*haty*) seems to have become the heart-soul (*ib*) once again.

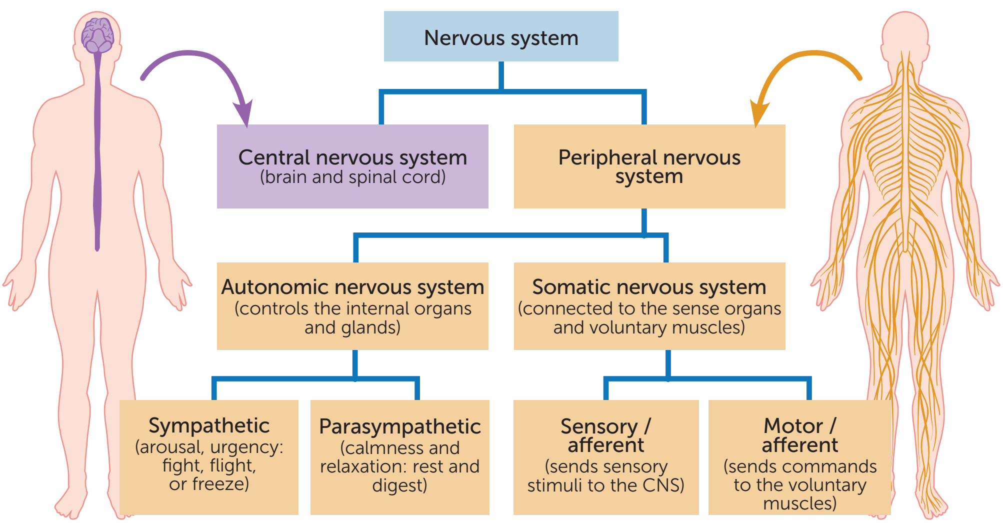
THE HEART AND THE BRAIN COMMUNICATE WITH EACH OTHER

> Why does our heart race when we feel strong emotions?

In the body, the heart and the brain are located some distance apart from each other, yet they communicate continuously with each other, so much so that, as we know, strong emotions can cause the heart to "race". Emotional activity generates and transmits signals to the heart that change how it functions. In fact, cardiac activity is heavily influenced by information from the brain associated with physical activity, warning signs, stress, and sleep. The most intense neural signals are induced by what we call **primordial, primal, or basic emotions** (fear, anxiety, anger, love, joy, etc.), which activate **alertness and immediate response mechanisms** and which have enabled our ancestors to survive since the emergence of the genus Homo (about 2.1 million years ago).

At the anatomical level, the nervous system is organized into two parts: the central nervous system (CNS) and the peripheral nervous system (PNS) [figure 2].

Figure 2 The nervous system



The **central nervous system** is made up of neurons and nerve fibers found in the **brain**, protected by the neurocranium or braincase, and in the **spinal cord**, contained in the vertebral column. Its **function is to control and process information** from other organs and the environment; it generates the most appropriate responses and transmits them to the rest of the body.

The **peripheral nervous system**, on the other hand, is made up of **receptors** and **nerves** and **sends information from both inside and outside the body**

to the CNS and, at the same time, transmits centrally processed nerve stimuli to the periphery.

The **autonomic nervous system** is part of the PNS and gets its name from the fact that it is independent of our volition. In fact, it regulates all the activities of our internal organs (such as the heart, lungs, and intestines) and certain muscles. It is through the autonomic nervous system that the brain controls the heart.

This system is divided into two branches, the sympathetic and the parasympathetic, which have antagonistic effects:

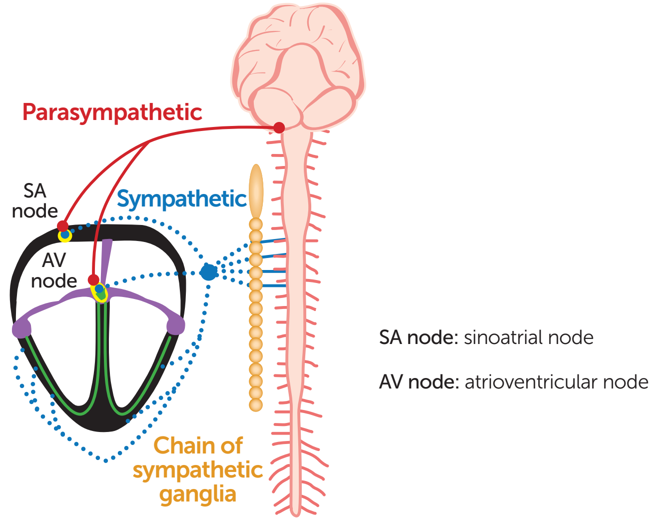
- the **sympathetic system** speeds up the heart rate and increases cardiac contraction, as well as exerting a constricting effect on other organs (for example, the arterial blood vessels and the intestines); it can also cause pallor, cold hands and feet, and an increase in arterial pressure (induced by arterial vasoconstriction);
- the **parasympathetic system** has the opposite effects: it slows down the heart rate and decreases cardiac contraction, exerting a dilating effect on the arterial vessels and the intestines.

The end result depends on whether sympathetic or parasympathetic activity is predominant in a given situation.

The **nerve cells (neurons)** of the sympathetic nervous system form connections with other neurons in the chain of **sympathetic ganglia** in the chest cavity. The most important of these is the **stellate ganglion**. The sympathetic ganglia integrate the neural information from the nervous system extrinsic to the heart with the information transmitted by the heart itself.

The **parasympathetic neurons** involved in controlling cardiac function, on the other hand, are located in the *medulla oblongata*. The **parasympathetic fibers** reach the heart via the vagus nerve and form a plexus of fibers interconnected with the surface of the heart (the epicardium). The neural communication pathways between the brain and the heart via the autonomic nervous system are illustrated in **figure 3**.

Figure 3 Neural communication between the brain and the heart via the autonomic nervous system



THE CONTROL CENTER

Communication between the heart and the brain depends on a **control center** located in the brain. It includes several brain structures: the medial prefrontal cerebral cortex, the insular cortex, the amygdala, the hypothalamus, etc. [figure 4].

Where is the control center?

The **insular cortex** is involved in generating a mental image of our physical state, which has an important influence on our basal emotional state. The **amygdala** is activated by negative emotions, generates immediate reactions to fearful emotions, and contributes to reinforcing memories related to negative emotions. In contrast, positive emotions tend to reduce activation of the amygdala. This structure is connected to the **hippocampus** and the **paraventricular nucleus** (located in the hypothalamus), which regulate the autonomic nervous system's response to different types of physical and psychological stress. This explains how anxiety and other negative emotions can

Figure 4 Brain structures

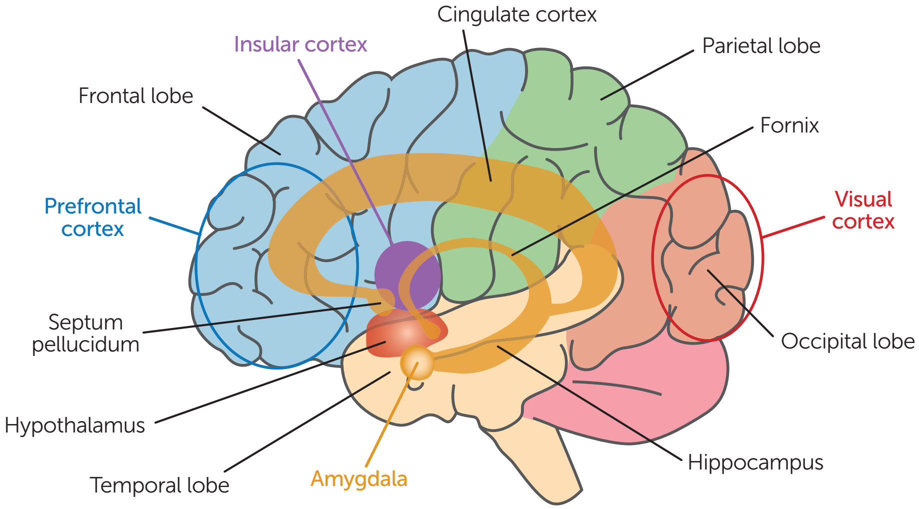
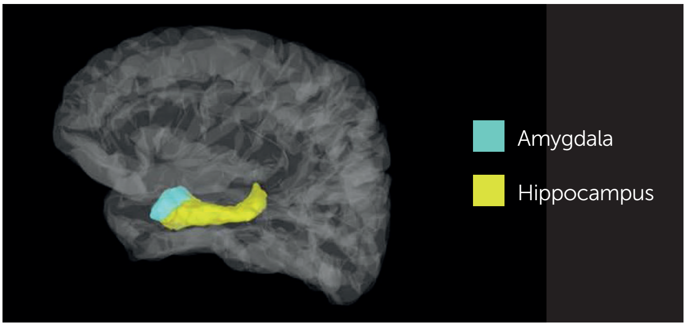


Figure 5 Connection between the amygdala and the hippocampus

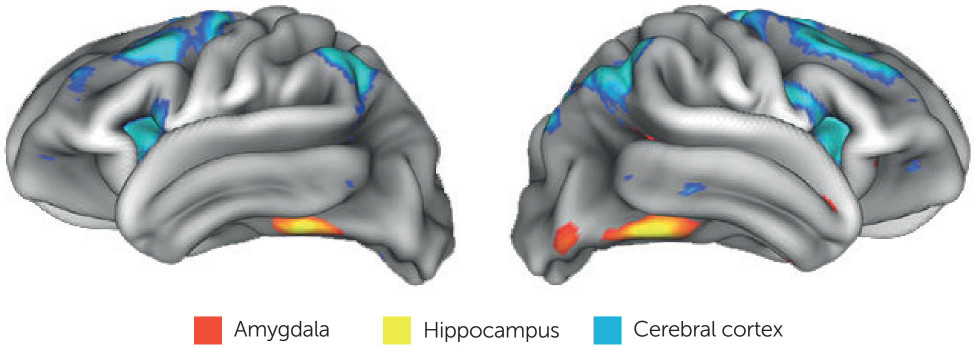


Source: Neuroscience News/Stephan Moratti.

speed up our heart rate through stimuli from the amygdala and the control center of the autonomic system located in the brain [**figure 5**].

Functional magnetic resonance imaging (fMRI) of the brain enables us to highlight the regions of the brain activated by different stimuli. When a subject looks at human faces, an activity that elicits emotions, we observe the activation of a region of the brain that includes the amygdala and the hippocampus

Figure 6 Illustration of an fMRI of a brain subjected to different emotional or mental stimuli



(colored red and yellow). On the other hand, when the subject performs memory tasks, activation of certain regions of the cerebral cortex (colored blue) is observed. Different emotional or mental activities thus activate different brain regions [**figure 6**].

THE SYMPATHETIC AND PARASYMPATHETIC NERVOUS SYSTEMS

As we have already mentioned, the heart is innervated by the sympathetic nervous system through neurons located in the upper thoracic portion of the spinal cord and connected with the sympathetic ganglia in the chest cavity. The **neurons of the sympathetic ganglia** innervate the cardiac conduction system, which generates the electrical stimulus that starts each heartbeat and transmits it from the upper part of the heart (the **atria**) to the lower part (the **ventricles**) [**figure 7**]. In addition, the sympathetic ganglia innervate the muscle tissue of the heart (the **myocardium**), increasing its contraction. The combined increase in heart rate and heart contraction serves to pump a greater volume of blood through the circulatory system and thus provide more oxygen to the organs of the body.

At the level of the heart cells, sympathetic neurons stimulate the secretion of chemicals called **neurotransmitters**, such as **noradrenaline** (also known as

Figure 7 Structure of the heart

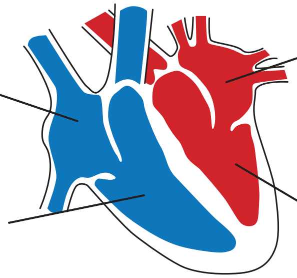
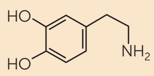
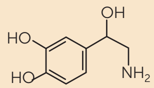
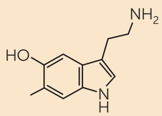
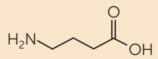
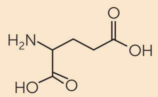
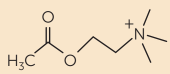


Figure 8 The main neurotransmitters

Dopamine		It controls alertness levels in many parts of the brain and presides over motor functions. It acts on the sympathetic nervous system, causing the heart rate to speed up and blood pressure to rise.
Norepinephrine (noradrenaline)		It acts directly on the sympathetic nervous system, regulating the response of certain functions (heart rate, breathing) to stressful or dangerous situations. It induces physical and mental alertness and regulates mood.
Serotonin		It regulates important physiological processes such as the sleep/wake cycle, the feeling of hunger/satiety, intestinal motility, mood, memory, and sexual desire. Defects in serotonin production are at the root of depressive disorders.
Gamma-aminobutyric acid (GABA)		It is the main inhibitory neurotransmitter of the central nervous system. It is also directly responsible for regulating muscle tone.
Glutamate		It is the main excitatory neurotransmitter. It is fundamental to the mechanisms of learning and long-term memory.
Endorphins, enkephalins (opioid peptides)	**Met-enkephalin:** Tyr-Gly-Gly-Phe-Met	They regulate feelings of pain and hunger.
Acetylcholine		It is responsible for nerve transmission in both the central nervous system and the peripheral nervous system. It controls the areas of the brain responsible for attention, memory, and learning functions.

norepinephrine) and **neuropeptide Y**, whose role is to transmit information to other cells [**figure 8**]. Noradrenaline activates the heart's beta-1 adrenergic receptors, which speed up the heart rate, while increasing contractility of the heart muscle at the same time. The sympathetic nervous system also controls the heart through the secretion of adrenaline (also known as epinephrine) from the adrenal gland. The time between nerve stimulation and the heart rate speeding up is 1.7 seconds.

Like the sympathetic system, the parasympathetic system also innervates both the cardiac conduction system and the myocardium. It stimulates the release of **acetylcholine**, which instantly slows down the heart rate, decreases the contractility of the heart muscle, and reduces intestinal vasoactive peptide, a hormone produced by the pancreas.

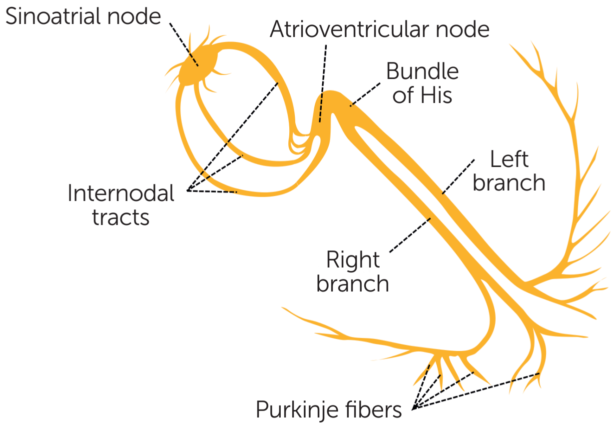
As we have seen, the system that regulates cardiac contraction is complex and involves the interaction of various parts of the nervous system that have the ability to produce different, even antagonistic effects. This enables the individual to respond effectively to various stimuli from both outside and inside the body. The issue of regulation is therefore very important and being able to build a model of it enables us to understand not only the substances that come into play, but also the effects they entail. Knowing how we can influence the behavior of this system, for example in situations when we need to bring it under control, is critical and can help save lives.

> What is the cardiac contraction regulation system for?

THE CARDIAC CONDUCTION SYSTEM

Each heart beat is the result of the electrical activation of the heart and the propagation of electrical stimulation to all regions of the heart muscle. These electrical phenomena are produced by the **cardiac conduction system**, which is formed by muscle cells with the ability to spontaneously depolarize (that is, change their electrical polarity). The spontaneous depolarization of these cells generates the electrical stimulus that is then transmitted to the entire heart through the conduction system. The anatomical structures that are part of it include the sinoatrial node (SA), the atrioventricular node (AV), the bundle of His, and the Purkinje fibers, which are divided into a left branch and a right branch [**figure 9**].

Figure 9 The cardiac conduction system



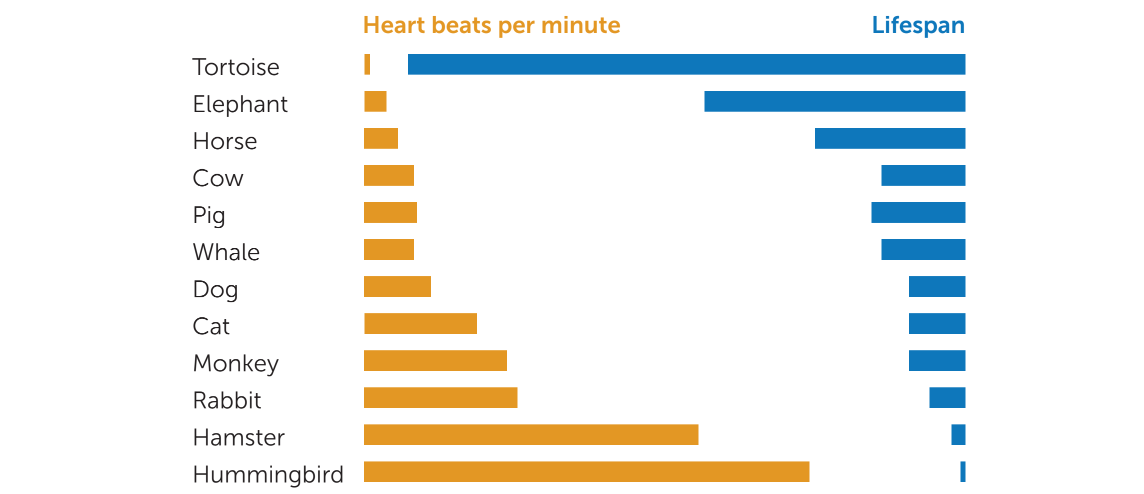
Since the SA node spontaneously depolarizes faster than the AV node, the bundle of His, or the Purkinje fibers, it determines the heart rate. This is why the SA node is also called the **natural pacemaker** and the normal heart rhythm is called the **sinus rhythm**. As we have seen, the functioning of the SA node is influenced by the sympathetic and parasympathetic impulses it receives, and thus by brain activity. However, the cells of the SA node maintain the heart rate at around 72 beats per minute even if detached from the nerves that control it.

When does the heart start beating?

The human heart begins to beat early, 16 days after conception. The heart of a healthy individual beats at a rate of 60 to 90 beats per minute (at rest). From this, we can calculate about 42 million beats per year and 3 billion beats over an average lifetime. The heart beat can speed up to over 100 beats per minute or slow down to about 20 beats per minute. Some healthy individuals, including many athletes, have a heart rate between 45 and 60 beats per minute. Athletic training speeds up the heart beat during exertion itself, but tends to slow it down between one bout of exertion and the next.

An interesting fact concerns the natural variability of the number of beats per minute among animal species [**figure 10**]. Small animals tend to have a

Figure 10 Relationship between the number of heart beats per minute and the mean lifespan in different animal species



faster heart rate, while larger ones have a slower rate, although the tortoise, for example, has a very slow heart rate. If we consider the different animal species globally, there seems to be an overall inverse relationship between heart beats per minute and average life span. The significance of this observation is unclear but it seems to suggest that the heart is, in a sense, "programmed" to beat a certain total number of times over a lifetime. If it beats faster, it reaches this beat limit earlier, so we could say that it "ages" quickly. But this is just a hypothesis. Other factors are likely to help explain this phenomenon.

THE HEART ALSO COMMUNICATES WITH THE BRAIN

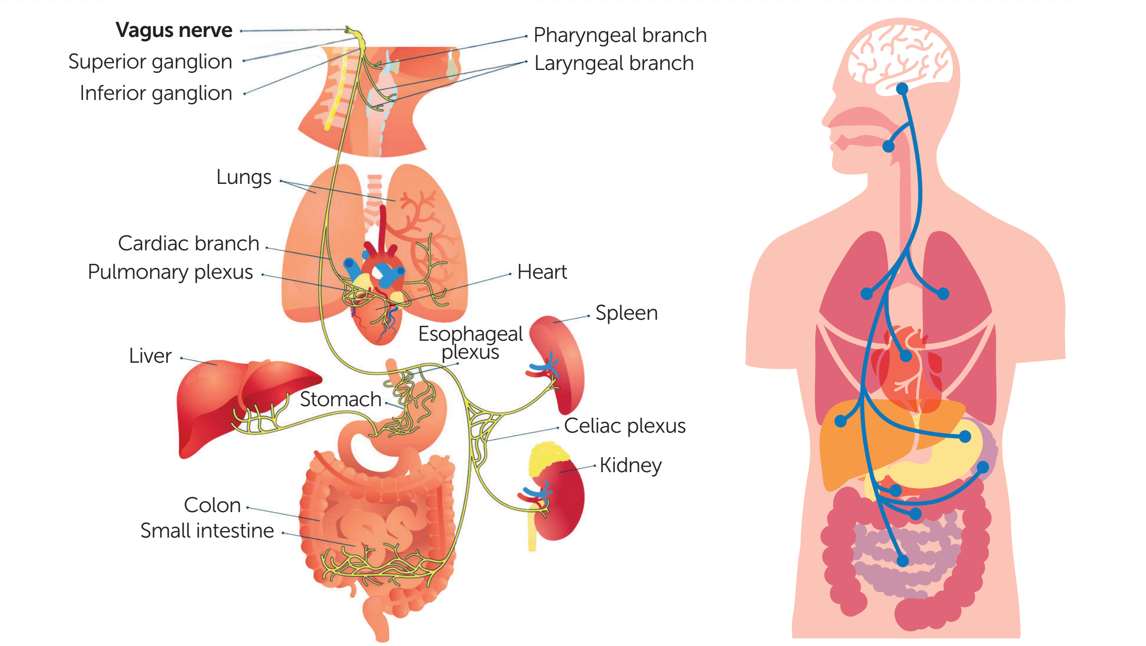
While the brain's influence on the heart is well known, the heart's influence on the brain is less well known. Communication between the two organs is actually bidirectional: descending and ascending.

The **ascending communication** uses the same nervous system structures that the **descending communication** uses, as well as chemicals circulating in the blood. The heart has its own system of **sensory nerve cells**, the **neurites**, which are activated by different physical and chemical stimuli from both the heart itself (heart rate, blood pressure, chemicals) and from other parts of the body. The heart's intrinsic nervous system integrates information from the extrinsic nervous system and from the sensory neurites found in the heart itself.

The **afferent sympathetic fibers** (i.e., those directed towards the brain) connect first with the nerve ganglia in the chest cavity, which process neural signals, then with the dorsal root ganglion and the spinal cord. The **nerve ganglia** in the chest cavity connect with the lungs and esophagus, and indirectly with many other organs, including the skin and arteries.

The **afferent parasympathetic fibers** connecting to the brain form the **vagus nerve** [**figure 11**], which is composed mainly of afferent fibers that connect with the *medulla*; from there, the information is transmitted to the subcortical regions (the thalamus, amygdala, etc.) and then to the upper regions of the cerebral cortex. The heart can control or activate certain brain

Figure 11 The vagus nerve



functions through these nerve pathways as well as through chemical signals, depending on the circumstances. This means that the heart can influence our perception of reality and our reactions.

HORMONES AND NEUROTRANSMITTERS

Both the brain and the heart produce and release hormones and neuropeptides into the blood, such as natriuretic peptides (brain natriuretic peptide and atrial natriuretic peptide), which control the homeostasis (stability) of extracellular fluid and affect blood pressure. Although to a lesser extent than the brain, the heart also produces oxytocin, which we will talk about later. Another hormone produced by the heart has recently been discovered: **GDF15**. This hormone is produced in excess by the hearts of children with severe congenital heart disease; it circulates in the blood and inhibits the action of growth hormone, contributing to the growth retardation observed in these children.

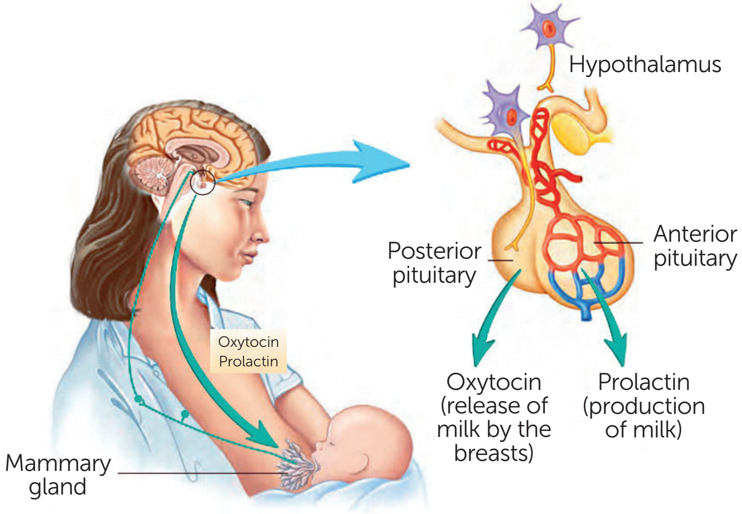
OXYTOCIN: "THE LOVE HORMONE"

Oxytocin is also known as the "love hormone." The secretion of this neuropeptide increases during the last stage of pregnancy and at moment of birth, stimulating the muscle contractions of the uterus. It also induces the secretion of breast milk during breastfeeding. Breastfeeding stimulates the hypothalamus to produce oxytocin, which is then secreted by the posterior pituitary [**figure 12**].

Why is oxytocin called the love hormone?

In both sexes, the production of oxytocin is stimulated by affectionate physical contact, sexual intercourse, or even just the sight of loved ones or small children, or by listening to music. Oxytocin promotes relational attachment and trust in people. Experiments on mice have shown that injecting oxytocin into the brains of female mice gives rise to maternal behavior in non-pregnant females. Conversely, injecting them with molecules that block oxytocin causes female mice to forget their young

Figure 12 The production of oxytocin stimulated by breastfeeding



when they move away. In males, a lack of oxytocin causes aggression and a lack of social attachments. Oxytocin also has the effect of reducing food consumption, which is why its therapeutic use to reduce obesity is being evaluated.

Oxytocin also exerts beneficial effects on the heart, such as arterial vasodilation and, consequently, a decrease in blood pressure. During a heart attack (caused by an interruption in the supply of oxygenated blood to the heart following the occlusion of a coronary artery), oxytocin seems to have a protective effect on the heart, reducing the severity of the heart attack.

In short, the brain (and to a lesser extent the heart) secretes oxytocin, a hormone with beneficial effects on both organs.

MENTAL STRESS AND HEART DISEASE

Anxiety and **depression** increase emotional instability and the likelihood of experiencing a heart attack. The relationship between psychological stress and cardiac circulatory collapse was first hypothesized by an anthropologist, Walter Cannon, in 1942. He hypothesized that death induced by voodoo and black magic among some primitive populations in Africa and other parts of the world could be caused by a psychogenic shock produced by fear, which would activate brain mechanisms that can lead to cardiac circulatory collapse. More recent studies have shown an increase in the number of heart attacks both during an earthquake and in the following days, thus suggesting the harmful effects of anxiety on the heart.

Other studies have shown that psychological stress and chronic depression, which particularly affects women at a ratio of 2:1, are responsible for a higher number of heart attacks than those caused by traditional risk factors (smoking, obesity, diabetes, and high blood pressure). With regard to risk factors, however, we must not forget that some can be modified through lifestyle changes or pharmacological therapies [**figure 13**].

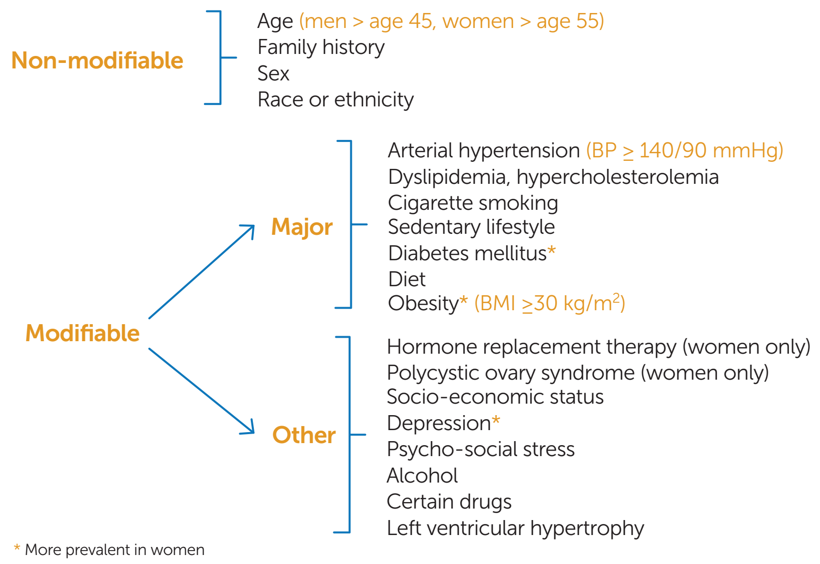
One interesting study found that mental stress, induced by having to perform mathematical calculations or memory tasks, caused a temporary disturbance in the cardiac circulation in some individuals; in the following four years, these same individuals had 5 times as many heart attacks as the others.

What is a Type A personality?

Furthermore, in 1959, two American cardiologists, Meyer Friedman and Ray Rosenman, observed that some individuals are particularly predisposed to cardiovascular disorders. This **personality**, which they called **Type A**, is characterized by excessive competitiveness, irritability, hostility, continuous desire for recognition, and propensity to put oneself through long working days.

Biologically, stress stimulates the sympathetic nervous system by increasing blood levels of noradrenaline and cortisol, heart rate, blood pressure, and vasoconstriction (a reversible reduction in the diameter of the arteries). In response to noradrenaline and cortisol, the amygdala alerts the entire nervous system to prepare for imminent danger, as well as reinforcing memories related to negative emotions. These alterations can create a vicious cycle that perpetuates stress. In addition, stress increases the number of white blood cells

Figure 13 Cardiovascular risk factors

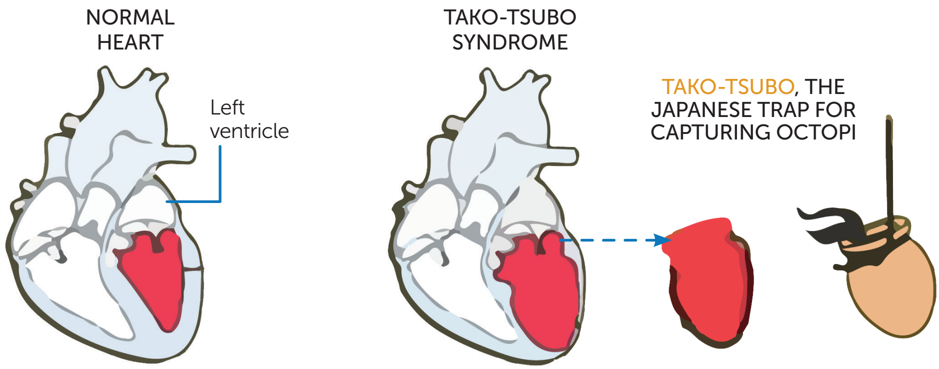


in the blood, which is a sign of inflammation, and the tendency of the blood to form clots (thrombi), which can cause a heart attack.

BROKEN HEART SYNDROME

A special case of heart damage caused by psychological or psycho-physical stress is what's known as broken heart syndrome, also called **stress cardiomyopathy** or ***Tako-tsubo* syndrome**. First described in Japan in 1991, this syndrome is characterized by severe chest pain, indistinguishable from a heart attack, and a rounding of the heart's shape reminiscent of the shape of the basket (*tsubo*) used by Japanese fishermen to fish for octopus (*tako*). This event is often caused by a negative emotion (bad news, fear, etc.), although some cases caused by a positive emotion have been described. The "ballooning" of the heart is essentially reversible. The biological mechanism is not entirely clear, but the release of noradrenaline into the blood caused by a strong emotion seems to play an important role, at least in some cases; very high levels of noradrenaline are actually toxic to heart cells [**figure 14**].

Figure 14 Tako-tsubo syndrome



EMOTIONAL WELL-BEING

Even in a state of physical rest, there are normally micro variations in the heart rate depending on the heart's response to physiological oscillatory signals, the most important of which is respiratory activity. There are two modes of heart rate variability: one is characterized by large, regular waves repeating in a harmoniously sequence (**coherence**), while the other is disordered, with waves that do not follow a particular pattern (**chaos**).

The **coherent mode** reflects the activation of the parasympathetic nervous system, as the oscillations of the heart rhythm depend on the slowing effect of the vagus nerve on the sinoatrial node, which is prevalent during exhalation. Deep, rhythmic respiratory activity thus favors coherent heart rate variability. The distance between the peaks and valleys of heart rate values is a measure of vagal activity. Interestingly, high coherent heart rate variability is associated with positive emotions (compassion, altruistic thoughts, etc.) and decreased anxiety. In line with these observations, the vagus nerve has been described as the biological system that facilitates caring for children and other individuals, and altruism in general. The vagus nerve has a high density of receptors for oxytocin which, as we have seen, induces positive emotions. In addition, this hormone increases the variability of the heart rate, thereby enhancing the effect of the vagus nerve.

The most surprising aspect, however, is the fact that it is possible to voluntarily increase heart rate variability through controlled respiratory activity, and that this translates into a positive emotional experience. The top panel of **figure 15** shows the heart rate of a healthy individual breathing spontaneously, in an uncontrolled way, at rest. The heart rate variability is chaotic. The bottom panel shows the heart rate of the same individual breathing rhythmically once every 10 seconds (i.e., at a frequency of 0.1 Hz). This technique is called **resonance breathing** because it induces particularly large and harmonious oscillations of the heart rate. Of note is that this aspect has also been seized by market research, leading to the inclusion of apps that invite you to breathe "in resonance" with some consumer products equipped with heart rate sensors!

What is resonance breathing?

Figure 15 Heart rate variability during spontaneous (uncontrolled) breathing and resonance breathing

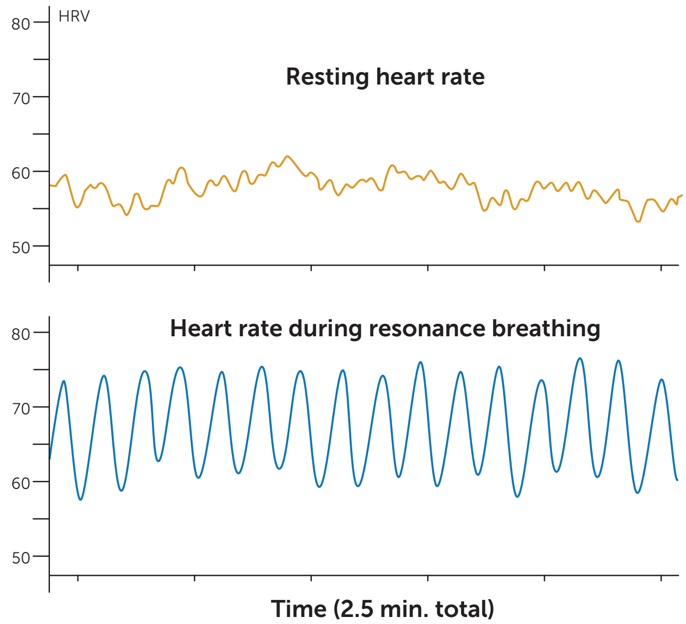
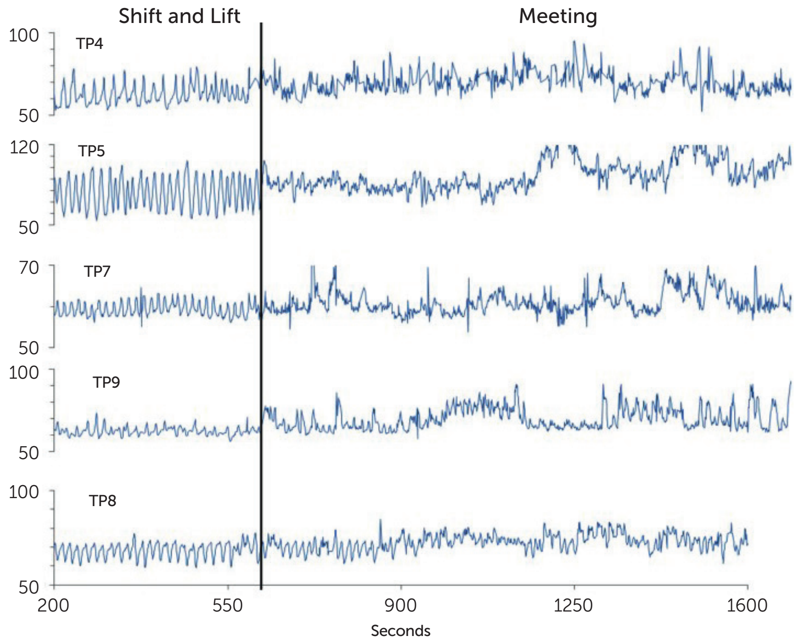


Figure 16 Heart rate variability in 5 individuals during controlled rhythmic breathing and during a subsequent work meeting



Source: McCraty R. Front Publ Health 2017.

Figure 16 illustrates another example of this phenomenon. It shows the heart rate variability in 5 individuals breathing rhythmically according to a technique called "Shift and Lift" before the start of a work meeting (indicated by the vertical black line). With only one exception (the second line from the bottom), the heart rate variability was more coherent during rhythmic breathing than during the meeting. Various contemplative activities such as **meditation** and **yoga** all involve controlled or carefully guided breathing. The emotional benefit associated with these activities may be due, at least in part, to activation of the vagus nerve induced by rhythmic breathing. A harmonious oscillation of the heart rhythm seems to stimulate the function of the prefrontal cerebral cortex, a region of the brain particularly sensitive to oscillations. Daily controlled breathing exercises over 3 months were effective in increasing heart rate variability and improving the emotional experience.

THE BRAIN AND THE HEART GENERATE MAGNETIC FIELDS

The brain and the heart both have electrical activity, which is typically recorded with an **electroencephalogram (EEG)** or **electrocardiogram (ECG)**, respectively. These methods record the electrical signals on the surface of the body that generate magnetic fields. In the human body, the heart generates the largest rhythmic magnetic field, which is in the order of nanotesla (about 100 times greater than the brain's magnetic field) and can be measured at about one meter away from the body by a magnetocardiogram (MCG, the magnetic equivalent of the ECG). The magnetic field of the human heart has a toroidal shape, the particular geometric shape illustrated in **figure 17**.

The heart radiates a series of pulsed magnetic waves (magnetic energy emitted in pulses) in which the time interval between two pulses of magnetic energy (i.e., between two peaks of the magnetic wave) varies in a complex way. These magnetic waves generate interference by interacting with tissues that can be magnetically polarized. **Figure 18** shows simultaneous ECG and MCG recordings on the surface of a healthy individual's chest during exhalation and inhalation. The electrical and magnetic activity are synchronous, indicating that the former generates the latter.

Figure 17 The magnetic field of the human heart

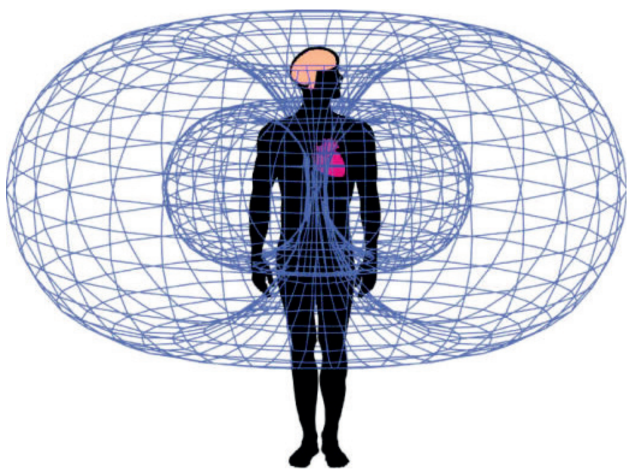
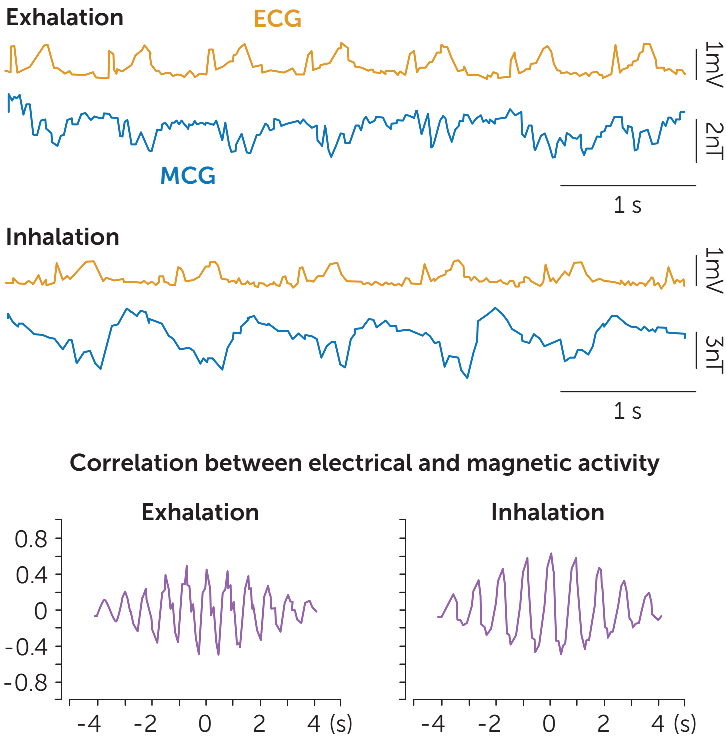


Figure 18 Electrocardiogram and magnetocardiogram of an individual during exhalation and inhalation: correlation between electrical activity and magnetic activity



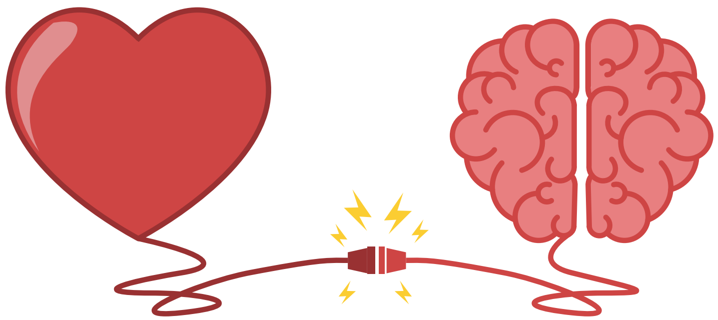
Source: Nakayama S. *et al.* PLoS One 2011.

CONCLUSIONS

This brief introduction shows how the heart and the brain, although anatomically far apart, exchange information through both the nervous system and circulating hormones. The heart, therefore, is much more than just a muscular pump that sends oxygenated blood throughout the body. We also saw that deep, rhythmic breathing can harmonize heart rate variability and, surprisingly, that this seems to improve the emotional experience. However, this latest observation is very recent and needs to be confirmed by further studies.

The connections between the heart and brain are complex and some of the aspects we discussed are not necessarily part of conventional basic knowledge regarding the heart. Such aspects, however, could have the merit of removing the heart from the conceptual isolation to which it has been relegated, as a stand-alone organ, seeing it instead through its interactions with the brain and other organs.

In fact, a systemic understanding of the human body cannot be reduced to detailed knowledge of how its individual parts function. On the contrary, understanding the body system and acquiring a certain level of wisdom regarding it (and ultimately regarding ourselves) is something that is cultivated through knowledge of the interactions between these parts. Effective and healthy communication between the different parts of the body is essential to promote the well-being of the individual: taking care of the heart and the brain therefore has a positive effect on both organs and has an impact on the entire body; we could even justifiably say that it has an impact on the individual and on their experience of reality. A good balance between these two very important organs, the heart and the brain, is therefore essential for our psychological and physical health!



Matters of… the heart

PART TWO

TEXTS

By the students of class 3C of the Tesserete Middle School:

Siro Bettini
Jonathan Biasca
Alessandro Cammarata
Soraya Campana
Mara Camponovo
Michelle Corti
Zoe Dell'Andrino
Camilla Farasini
Alex Gelpi
Tristan Knupfer
Laura Morosoli
Alice Orsi
Anna Reverberi
Sophie Riavis
Priamo Riva
Amélie Ruggeri
Emma Stefanizzi
Eithlyn Stucki

Under the coordination of the teachers:

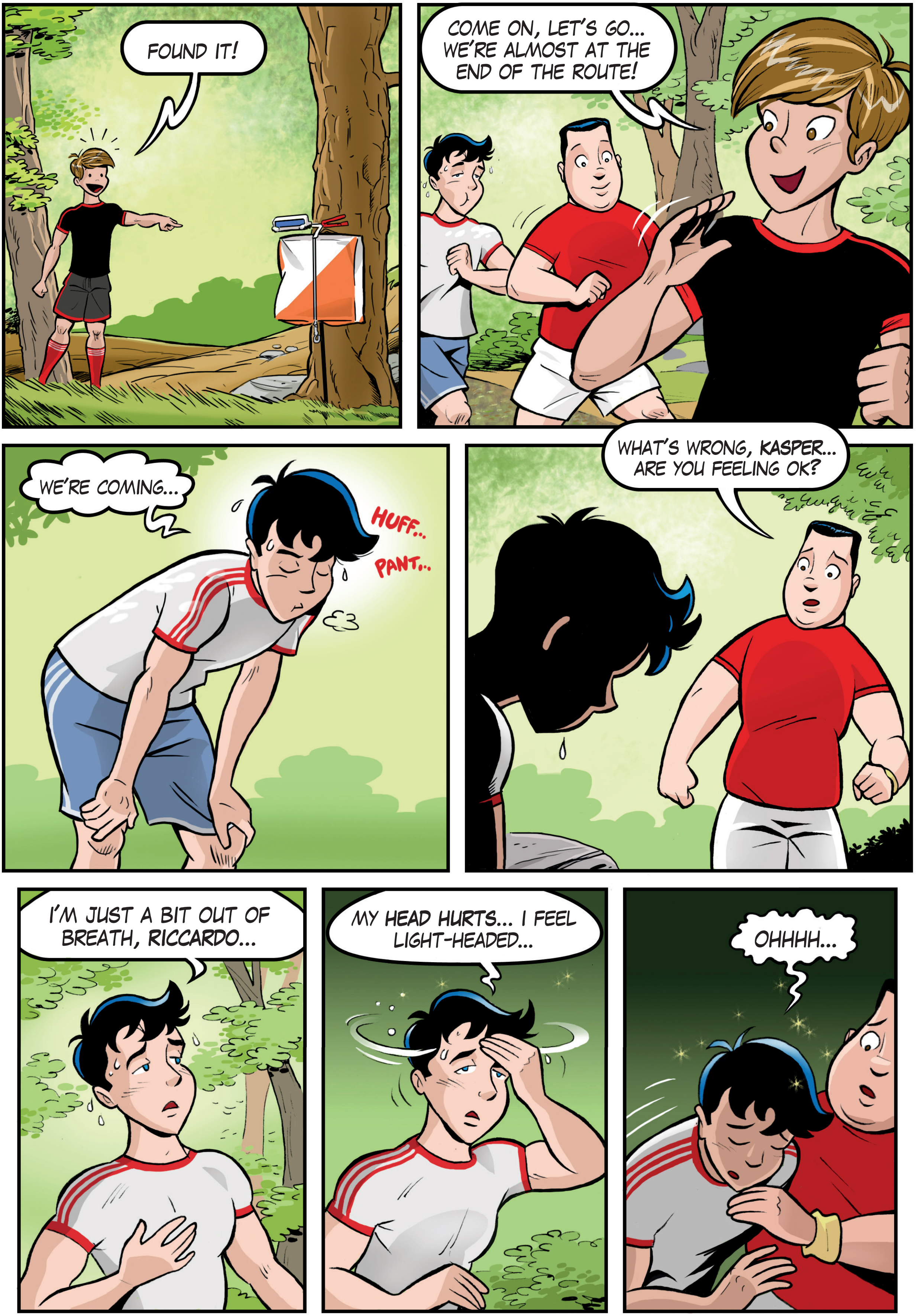
Pamela Mobilia-Monti (natural sciences teacher)
Martina Cameroni (Italian teacher)

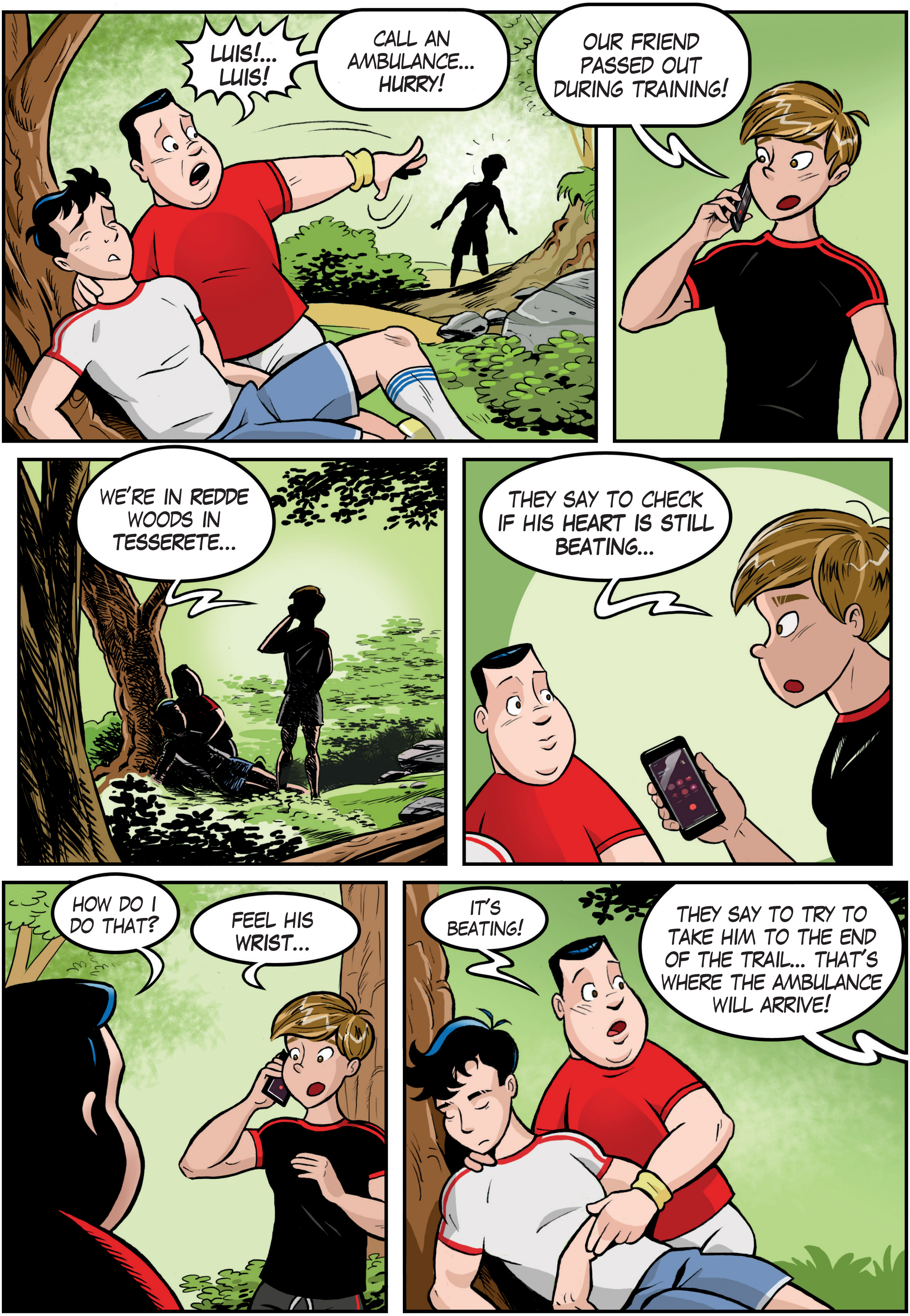
Tesserete Middle School
Via Gola di Lago - 6950 Tesserete
Ticino - Switzerland
www.smtesserete.ti.ch
decs-sm.tesserete@edu.ti.ch
Head teacher: Giorgio Cesarini

ILLUSTRATIONS

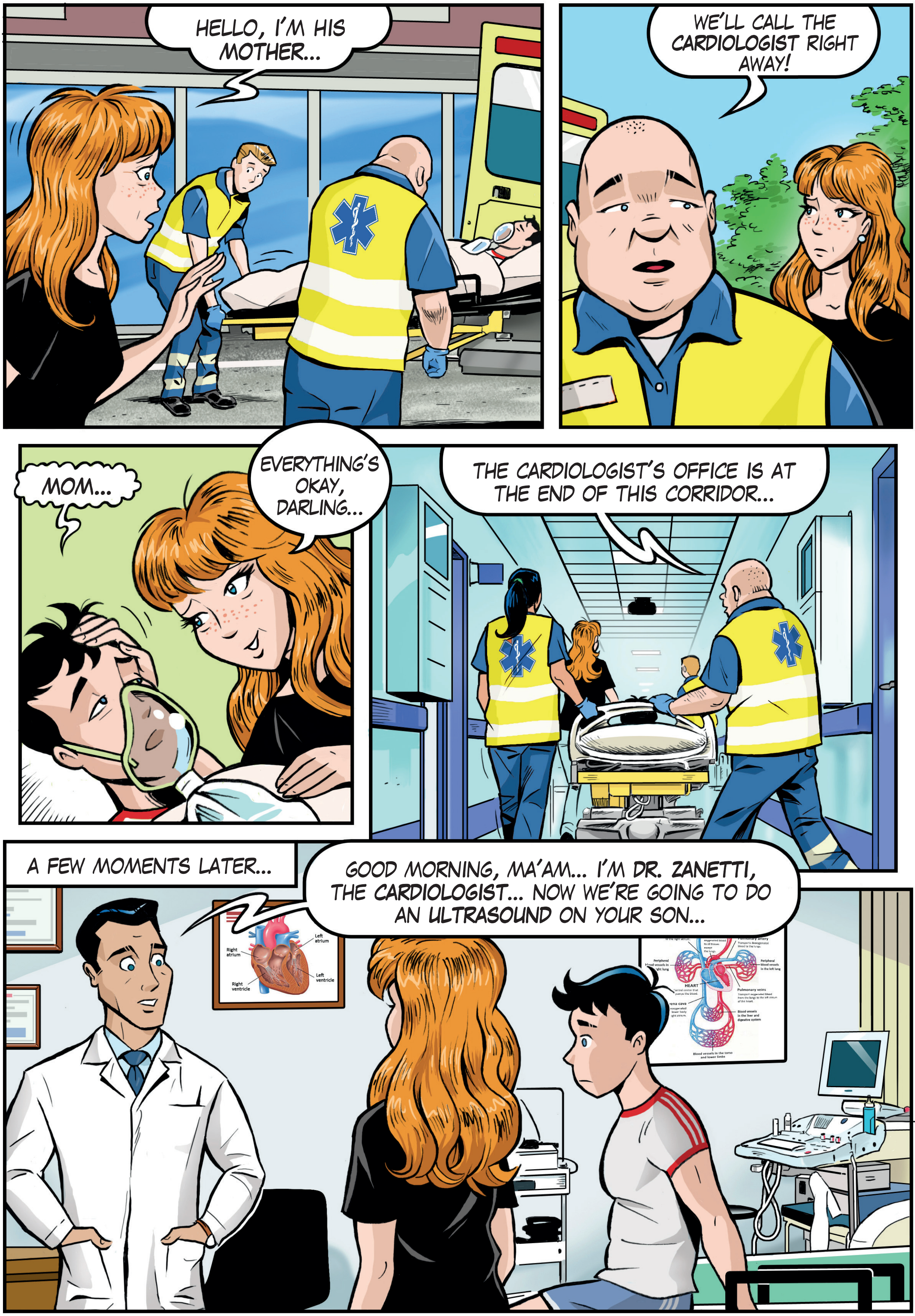
By Alessandro Telve for the Scuola Romana dei Fumetti.

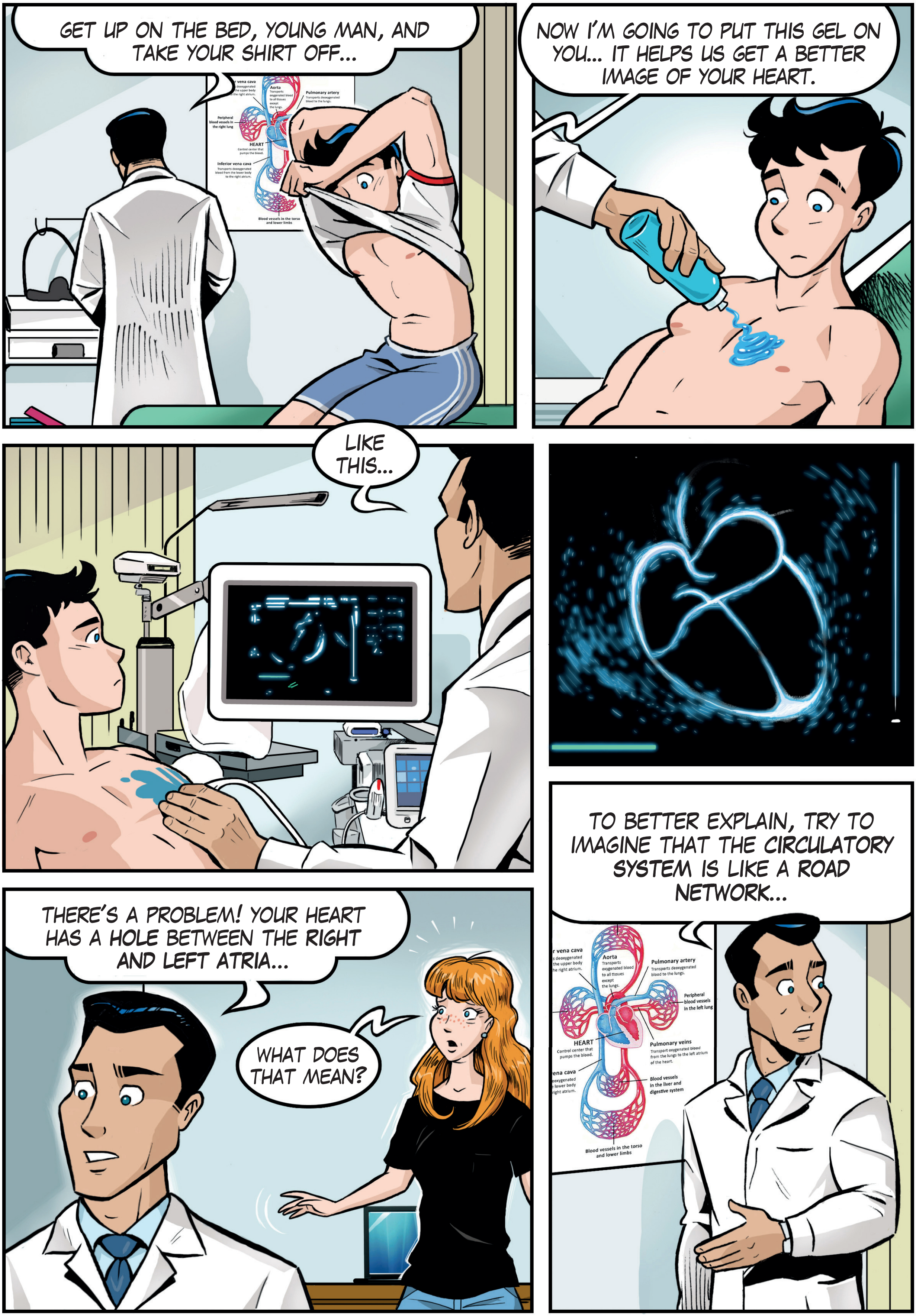

MATTERS OF...
THE HEART
REDDE WOODS... ORIENTEERING TRAINING...
IS IT FAR TO POINT NUMBER EIGHT?
NO, WE SHOULD BE NEARLY THERE...
OVER THERE...

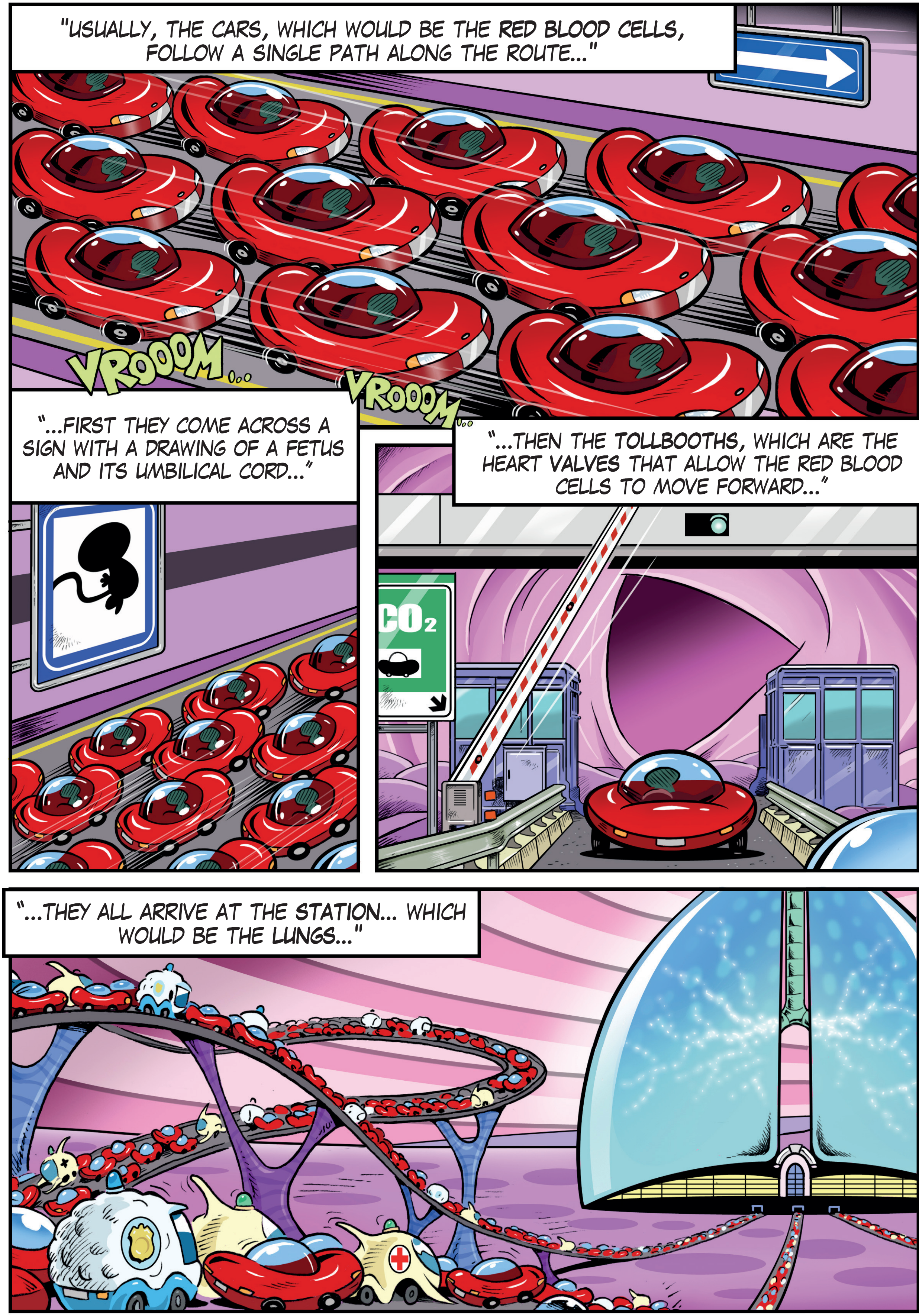

FOUND IT!
COME ON, LET'S GO... WE'RE ALMOST AT THE END OF THE ROUTE!
WE'RE COMING...
HUFF...
PANT...
WHAT'S WRONG, KASPER... ARE YOU FEELING OK?
I'M JUST A BIT OUT OF BREATH, RICCARDO...
MY HEAD HURTS... I FEEL LIGHT-HEADED...
OHHHH...

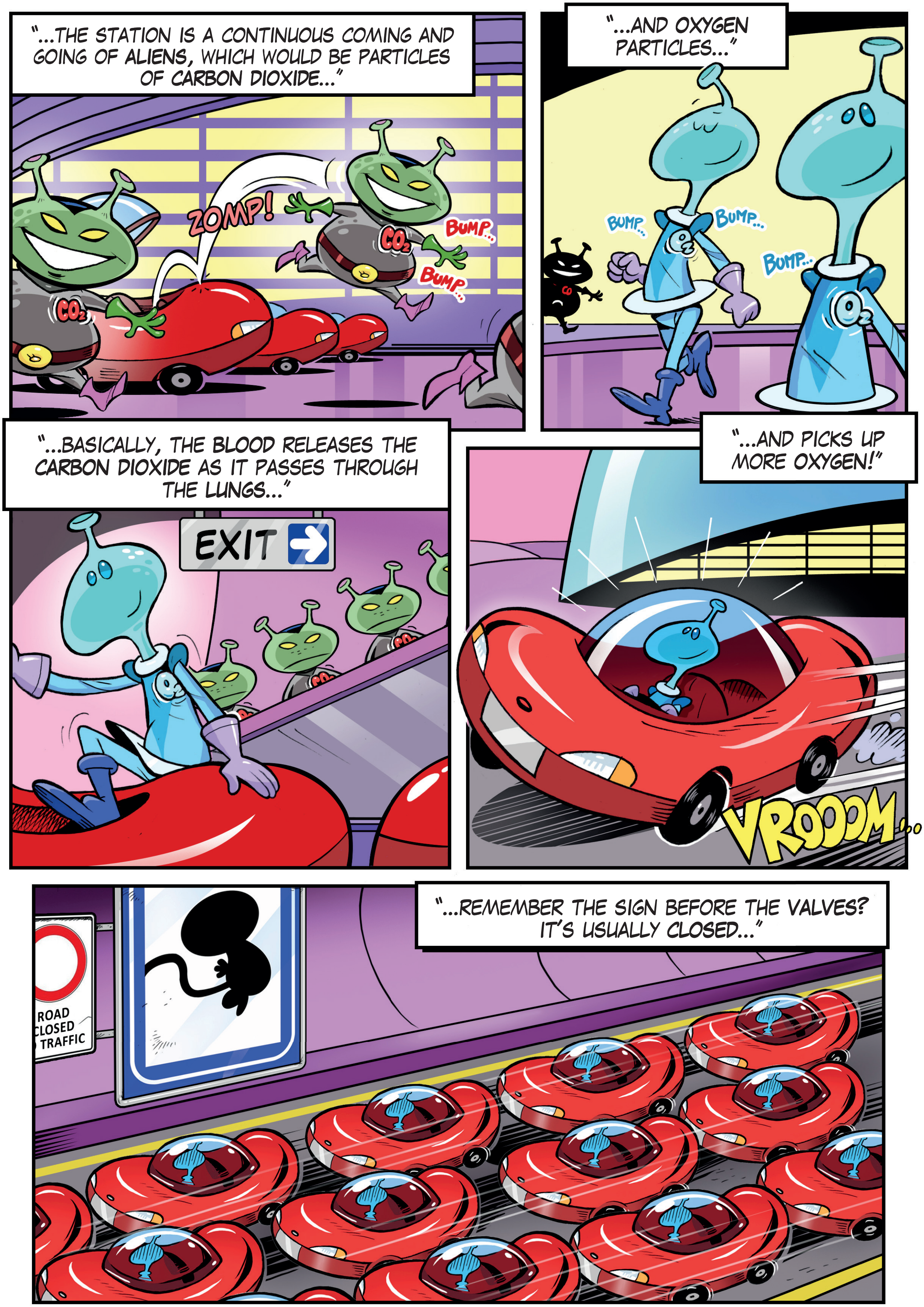

LUIS!... LUIS!
CALL AN AMBULANCE... HURRY!
OUR FRIEND PASSED OUT DURING TRAINING!
WE'RE IN REDDE WOODS IN TESSERETE...
THEY SAY TO CHECK IF HIS HEART IS STILL BEATING...
HOW DO I DO THAT?
FEEL HIS WRIST...
IT'S BEATING!
THEY SAY TO TRY TO TAKE HIM TO THE END OF THE TRAIL... THAT'S WHERE THE AMBULANCE WILL ARRIVE!

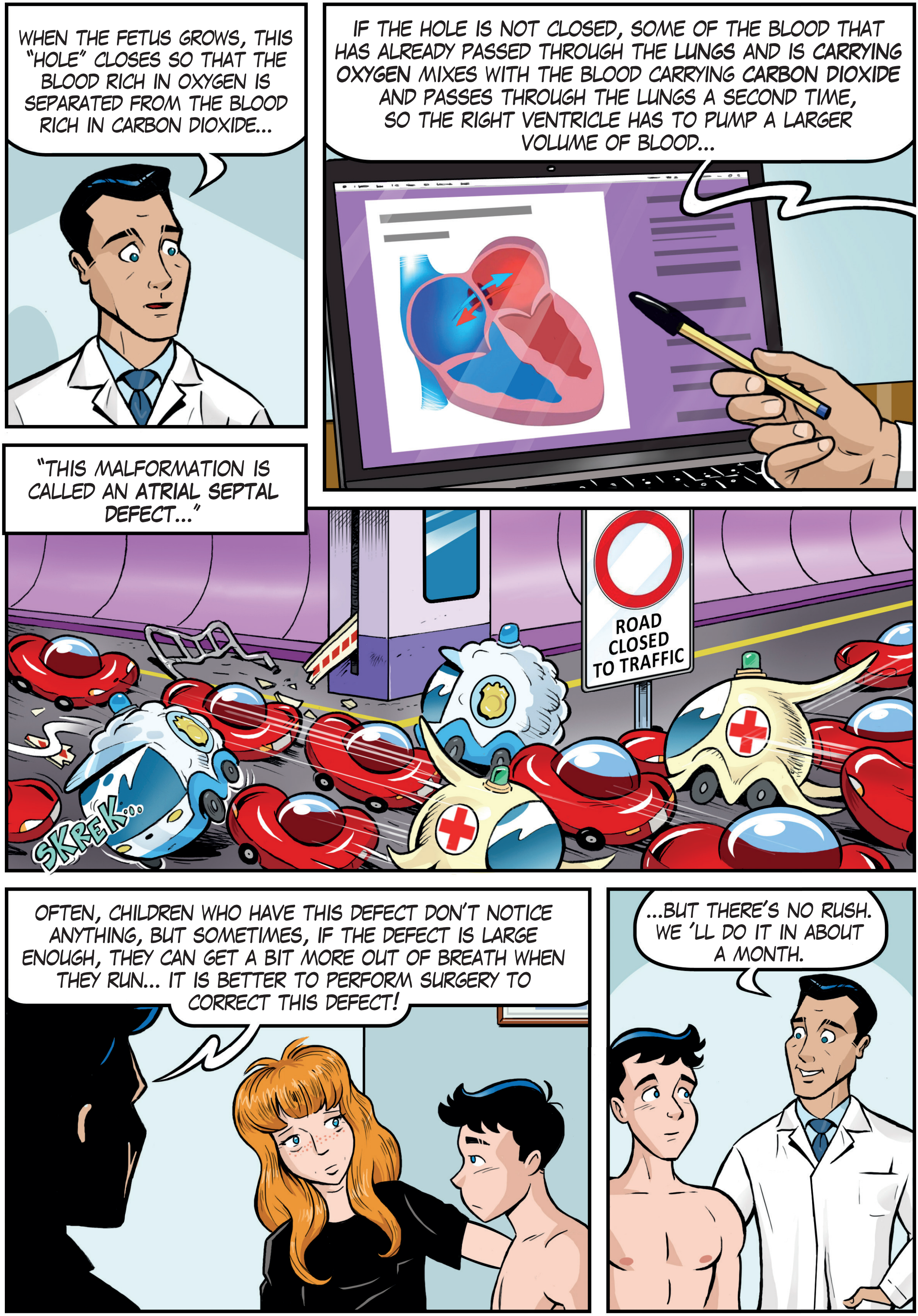

LET'S GO CAREFULLY... HOLD ON, KASPER, YOU CAN MAKE IT!
JUST STAY CONSCIOUS A BIT LONGER...
A LITTLE WHILE LATER...
DON'T WORRY, GUYS... EVERYTHING'S GOING TO BE FINE!
HAVE YOU TOLD HIS PARENTS YET?
NO...
WE'LL CALL THEM!
WEEOOOW
100
AMBULANCE
WEEOOOW

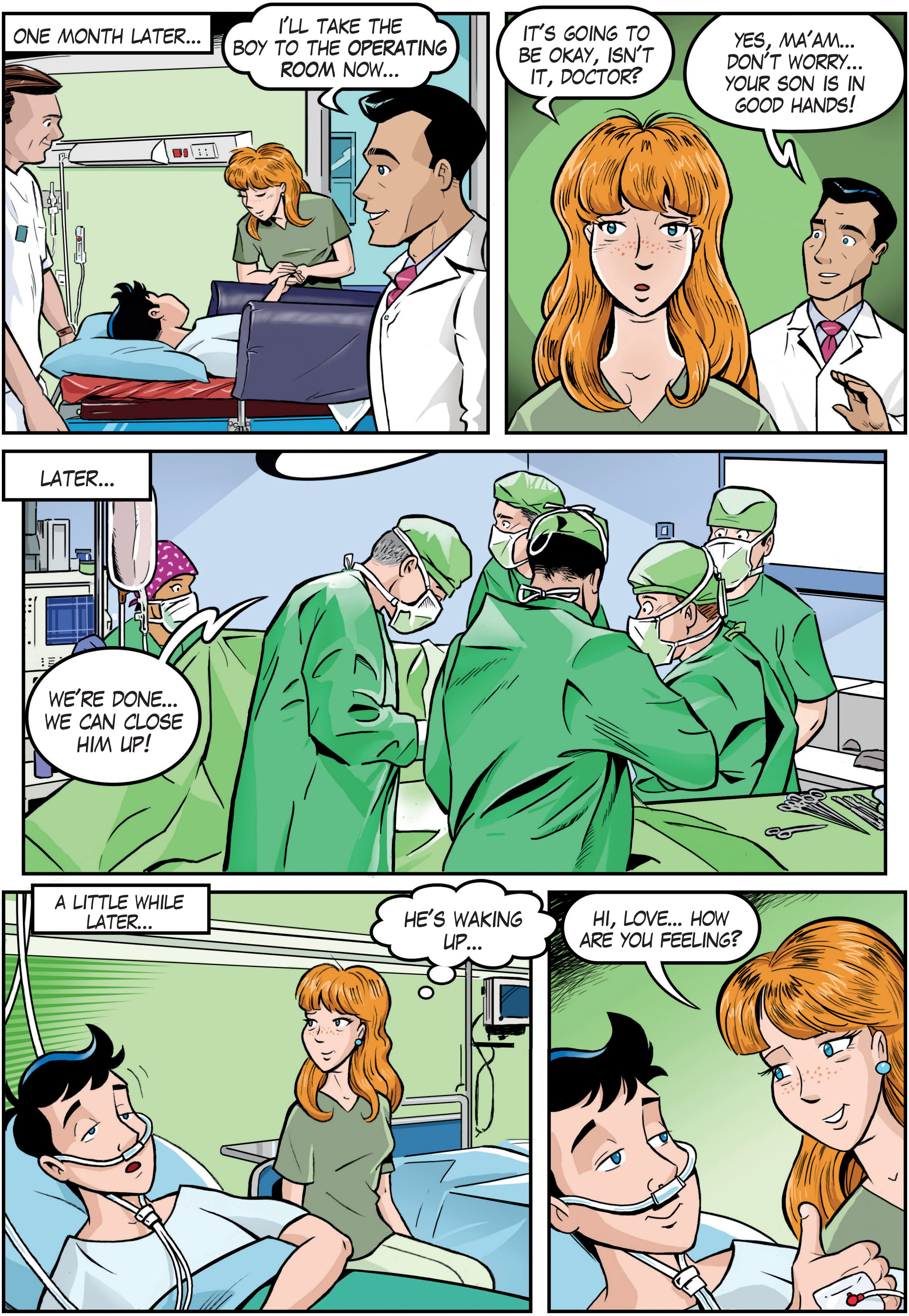

HELLO, I'M HIS MOTHER...
WE'LL CALL THE CARDIOLOGIST RIGHT AWAY!
MOM...
EVERYTHING'S OKAY, DARLING...
THE CARDIOLOGIST'S OFFICE IS AT THE END OF THIS CORRIDOR...
A FEW MOMENTS LATER...
GOOD MORNING, MA'AM... I'M DR. ZANETTI, THE CARDIOLOGIST... NOW WE'RE GOING TO DO AN ULTRASOUND ON YOUR SON...
Right atrium
Left atrium
Right ventricle
Left ventricle
HEART
Pulmonary veins

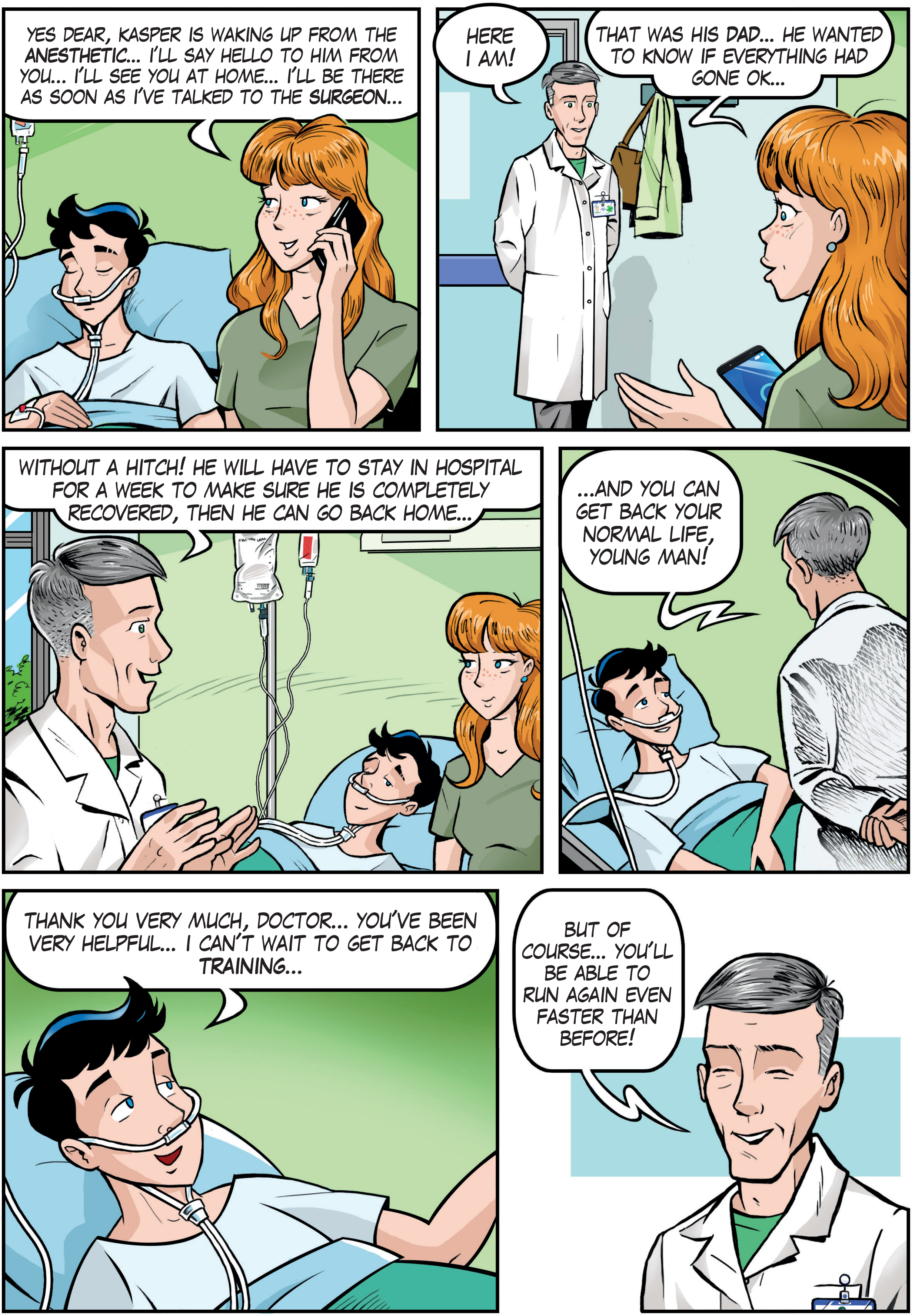

GET UP ON THE BED, YOUNG MAN, AND TAKE YOUR SHIRT OFF...
NOW I'M GOING TO PUT THIS GEL ON YOU... IT HELPS US GET A BETTER IMAGE OF YOUR HEART.
LIKE THIS...
THERE'S A PROBLEM! YOUR HEART HAS A HOLE BETWEEN THE RIGHT AND LEFT ATRIA...
WHAT DOES THAT MEAN?
TO BETTER EXPLAIN, TRY TO IMAGINE THAT THE CIRCULATORY SYSTEM IS LIKE A ROAD NETWORK...

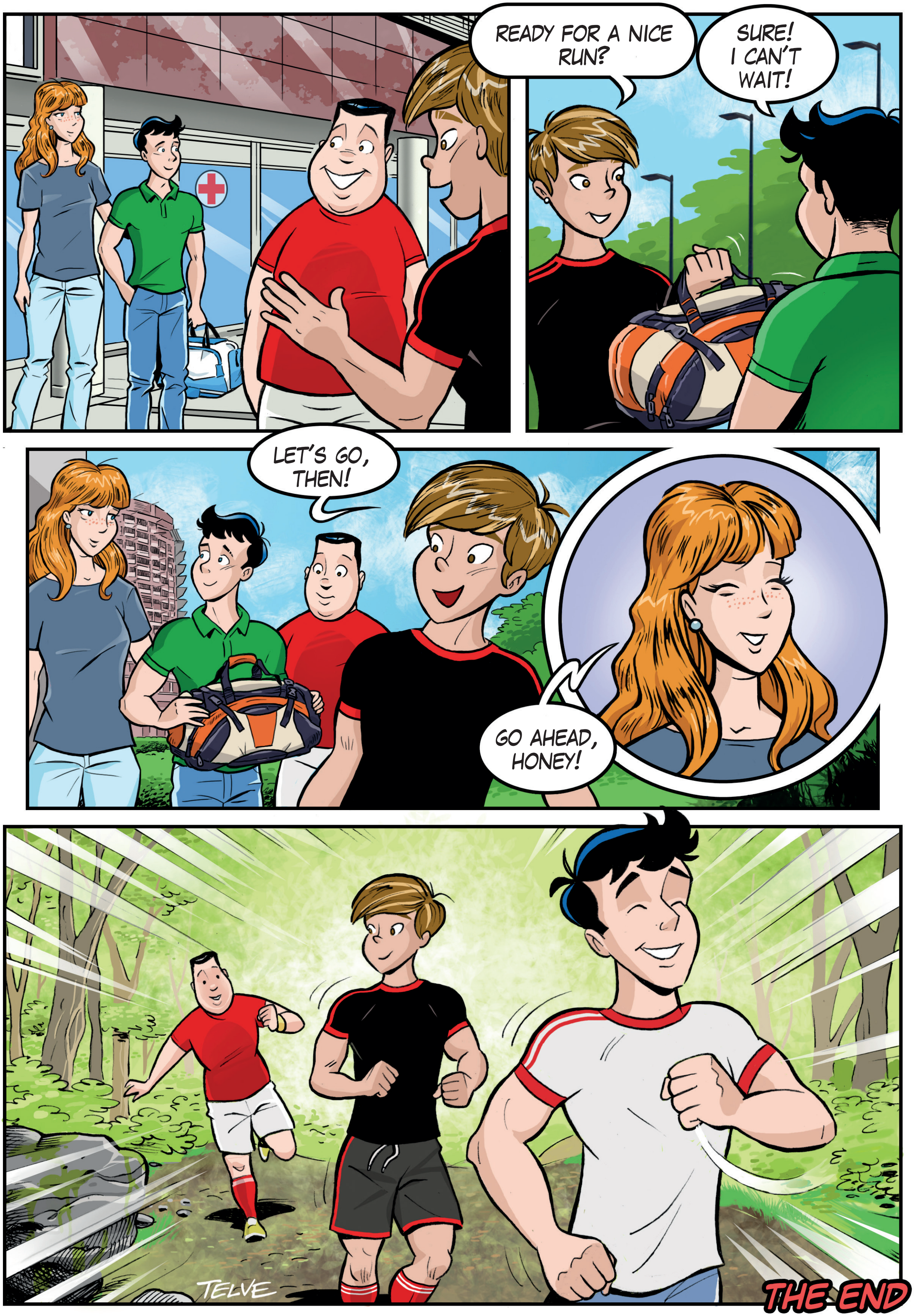

"USUALLY, THE CARS, WHICH WOULD BE THE RED BLOOD CELLS, FOLLOW A SINGLE PATH ALONG THE ROUTE..."
VROOOM...
VROOOM...
"...FIRST THEY COME ACROSS A SIGN WITH A DRAWING OF A FETUS AND ITS UMBILICAL CORD..."
"...THEN THE TOLLBOOTHS, WHICH ARE THE HEART VALVES THAT ALLOW THE RED BLOOD CELLS TO MOVE FORWARD..."
CO2
"...THEY ALL ARRIVE AT THE STATION... WHICH WOULD BE THE LUNGS..."


"...THE STATION IS A CONTINUOUS COMING AND GOING OF ALIENS, WHICH WOULD BE PARTICLES OF CARBON DIOXIDE..."
ZOMP!
CO_2
CO_2
BUMP...
BUMP...
"...AND OXYGEN PARTICLES..."
BUMP...
BUMP...
BUMP...
"...BASICALLY, THE BLOOD RELEASES THE CARBON DIOXIDE AS IT PASSES THROUGH THE LUNGS..."
EXIT
"...AND PICKS UP MORE OXYGEN!"
VROOOM...
"...REMEMBER THE SIGN BEFORE THE VALVES? IT'S USUALLY CLOSED..."
ROAD
CLOSED
TRAFFIC


WHEN THE FETUS GROWS, THIS "HOLE" CLOSES SO THAT THE BLOOD RICH IN OXYGEN IS SEPARATED FROM THE BLOOD RICH IN CARBON DIOXIDE...
IF THE HOLE IS NOT CLOSED, SOME OF THE BLOOD THAT HAS ALREADY PASSED THROUGH THE LUNGS AND IS CARRYING OXYGEN MIXES WITH THE BLOOD CARRYING CARBON DIOXIDE AND PASSES THROUGH THE LUNGS A SECOND TIME, SO THE RIGHT VENTRICLE HAS TO PUMP A LARGER VOLUME OF BLOOD...
"THIS MALFORMATION IS CALLED AN ATRIAL SEPTAL DEFECT..."
ROAD CLOSED TO TRAFFIC
SKREK...
OFTEN, CHILDREN WHO HAVE THIS DEFECT DON'T NOTICE ANYTHING, BUT SOMETIMES, IF THE DEFECT IS LARGE ENOUGH, THEY CAN GET A BIT MORE OUT OF BREATH WHEN THEY RUN... IT IS BETTER TO PERFORM SURGERY TO CORRECT THIS DEFECT!
...BUT THERE'S NO RUSH. WE 'LL DO IT IN ABOUT A MONTH.


ONE MONTH LATER...
I'LL TAKE THE BOY TO THE OPERATING ROOM NOW...
IT'S GOING TO BE OKAY, ISN'T IT, DOCTOR?
YES, MA'AM... DON'T WORRY... YOUR SON IS IN GOOD HANDS!
LATER...
WE'RE DONE... WE CAN CLOSE HIM UP!
A LITTLE WHILE LATER...
HE'S WAKING UP...
HI, LOVE... HOW ARE YOU FEELING?


YES DEAR, KASPER IS WAKING UP FROM THE ANESTHETIC... I'LL SAY HELLO TO HIM FROM YOU... I'LL SEE YOU AT HOME... I'LL BE THERE AS SOON AS I'VE TALKED TO THE SURGEON...
HERE I AM!
THAT WAS HIS DAD... HE WANTED TO KNOW IF EVERYTHING HAD GONE OK...
WITHOUT A HITCH! HE WILL HAVE TO STAY IN HOSPITAL FOR A WEEK TO MAKE SURE HE IS COMPLETELY RECOVERED, THEN HE CAN GO BACK HOME...
...AND YOU CAN GET BACK YOUR NORMAL LIFE, YOUNG MAN!
THANK YOU VERY MUCH, DOCTOR... YOU'VE BEEN VERY HELPFUL... I CAN'T WAIT TO GET BACK TO TRAINING...
BUT OF COURSE... YOU'LL BE ABLE TO RUN AGAIN EVEN FASTER THAN BEFORE!


READY FOR A NICE RUN?
SURE! I CAN'T WAIT!
LET'S GO, THEN!
GO AHEAD, HONEY!
TELVE
THE END

GLOSSARY

Acetylcholine A substance produced by our body that is responsible for nerve transmission at the level of the central and peripheral nervous systems. It is one of the major neurotransmitters. It controls the areas of the brain responsible for attention, memory, and learning functions. It slows the heart rate and decreases the contractility of the heart muscle.

Amygdala A small oval formation of gray matter located in the anterior part of the medial temporal lobe of the two cerebral hemispheres. It is connected to the hippocampus and the paraventricular nucleus, which regulate the autonomic nervous system's response to different types of physical and psychological stress. It is activated by negative emotions, generates immediate reactions to fearful emotions, and contributes to reinforcing memories related to negative emotions. In contrast, positive emotions tend to reduce activation of the amygdala.

Atrioventricular node An anatomical structure that is part of the electrical conduction system of the heart, along with the sinoatrial node (SA), the bundle of His, and the Purkinje fibers. It is responsible for delaying the electrical impulse in the passage from atrium to ventricle.

Atrium The (right and left) atria are the two upper chambers of the human heart and are located above the two ventricles; they are separated by the interatrial septum.

Autonomic nervous system This is part of the peripheral nervous system and is independent of our volition. In fact, it regulates all the activities of our internal organs (such as the heart, lungs, and intestines) and certain muscles. It is divided into two branches: the sympathetic system and the parasympathetic system, which have antagonistic effects.

Cardiomyopathy A condition that affects the heart muscle, reducing the efficiency of the heart, which struggles to pump blood to the rest of the body.

Central nervous system Along with the peripheral nervous system, it makes up the "nervous system". It is made up of neurons and nerve fibers that are located in the brain (protected by the neurocranium) and in the spinal cord (contained in the vertebral column). Its function is to control and process information from other organs and the environment; it generates the most appropriate responses and transmits them to the rest of the body.

Electrocardiogram (ECG) A diagnostic examination that records and graphically reproduces the electrical activity of the heart while it is functioning. It provides information about the heart rhythm, heart rate, and the presence of any cardiac conditions.

Electroencephalogram (EEG) A diagnostic examination that measures the electrical activity of the brain through electrodes placed on the scalp, displaying it on a screen in the form of a series of waves.

Ganglion A nerve structure that is part of the peripheral nervous system and looks like a small round swelling located along the course of the nerves.

GDF15 A recently discovered hormone that is produced in excess by the hearts of children with severe congenital heart disease. It circulates in the blood and inhibits the action of growth hormone, contributing to growth retardation.

Heart rate The number of times the heart beats in a minute (bpm). Changes in the heart rate depend on the nerve stimuli received by the heart, chemicals (noradrenaline, etc.), and the heart's response to physiological oscillatory signals, the most important of which is respiratory activity. An adult's resting heart rate is about 60-90 bpm. Bradycardia is defined as the presence of a slow heartbeat, usually below 60 bpm. It is called tachycardia, on the other hand, when the heart rate is above 100 bpm.

Hippocampus A brain structure that is located in the inner region of the temporal lobe. Together with the paraventricular nucleus (located in the hypothalamus), it regulates the autonomic nervous system's response to different types of physical and mental stress.

Hormone A chemical produced within the body that is released into the bloodstream and activates responses in cells located at various distances from its site of production.

Hypothalamus A structure of the central nervous system located between the two cerebral hemispheres. It is made up of numerous nuclei that regulate and control peripheral autonomic mechanisms, endocrine activity, and various somatic functions such as thermoregulation, sleep, hydro-saline balance, and food intake.

Insular cortex The part of the cerebral cortex that lies between the temporal lobe and the frontal lobe. It is involved in generating a mental image of our physical state, which has an important influence on our basal emotional state.

Magnetic Resonance Imaging (MRI) A non-invasive diagnostic examination that provides detailed images of the inside of the human body (internal organs, skeleton, joints, etc.) using magnetic fields.

Magnetocardiogram An instrument used to measure the magnetic fields produced by the electrical activity of the heart.

Medulla oblongata	Also simply called the medulla, it is the final part of the brainstem, located above the spinal cord. It is formed of bundles of nerve fibers that connect the spinal cord with the brain and is shaped like an upside-down cone. The parasympathetic neurons involved in controlling cardiac function are located in the *medulla oblongata*.
Myocardium	The muscle tissue of the heart, which forms the structure of the walls and makes it work like a pump. It is made up of 70% muscle fibers and 30% blood vessels and connective tissue.
Neurites	Sensory nerve cells in the heart that are activated by different physical and chemical stimuli from both the heart itself (heart rate, pressure, chemicals) and other parts of the body.
Neuron	A nerve cell that serves to produce and exchange signals. The central nervous system is made up of these cells, along with nerve fibers.
Neuropeptide	A small protein molecule that is processed and circulated by nerve cells in response to a stimulus. Its function is to transmit or modulate nerve signals.
Noradrenaline/norepinephrine	A hormone and one of the main neurotransmitters. It activates the heart's beta-1 adrenergic receptors, which speed up the heart rate, while increasing the contractility of the heart muscle at the same time. It acts directly on the sympathetic nervous system, regulating the response of certain functions (heart rate, breathing) to stressful or dangerous situations. It induces physical and mental alertness and regulates mood.
Oxytocin	A hormone produced by the hypothalamus and secreted by the pituitary. In women, its secretion increases during the last stage of pregnancy and at the moment of birth, stimulating the muscle contractions of the uterus. It also induces the secretion of breast milk during breastfeeding. It is also called the "love hormone" because, in both sexes, its production is stimulated by affectionate physical contact, sexual intercourse, or even just by the sight of loved ones or small children, or by listening to music.

Parasympathetic nervous system	One of the two branches into which the autonomic nervous system is divided. It slows down the heart rate and decreases cardiac contraction, exerting a dilating effect on the arterial vessels and the intestines.
Paraventricular nucleus	A group of hypothalamic cells. It contains different types of neurons, which are activated by stressful stimuli and/or physiological changes.
Peripheral nervous system	Along with the central nervous system, it makes up the "nervous system". Consisting of receptors and nerves, it sends information from both inside and outside the body to the central nervous system and, at the same time, transmits centrally processed nerve stimuli to the periphery.
Prefrontal cerebral cortex	The anterior part of the frontal lobe of the brain, located in front of the primary motor cortex and the premotor cortex. Together with other brain structures (the insular cortex, amygdala, hypothalamus, etc.), it constitutes the control center that regulates communication between the heart and the brain.
Resonance breathing	A breathing technique that induces particularly large and harmonious oscillations of heart rate variability.
Sinoatrial node	An anatomical structure that is part of the electrical conduction system of the heart, along with the atrioventricular node (AV), the bundle of His, and the Purkinje fibers. It is also called the natural pacemaker because it determines the heart rhythm. Its function is influenced by the sympathetic and parasympathetic impulses it receives, and thus by brain activity.
Spinal cord	Contained in the vertebral column, it is a fragile, tube-shaped structure that is part of the central nervous system. It is formed of nerve fibers that carry information from the brain to other organs and other parts of the body and vice versa.

Sympathetic nervous system	One of the two branches into which the autonomic nervous system is divided. It speeds up the heart rate and increases cardiac contraction, as well as exerting a constricting effect on other organs (for example, the arterial blood vessels and the intestines); it can cause increased blood pressure.
Thrombus	A blood clot that forms inside arterial or venous blood vessels or in the heart chambers and hinders normal blood circulation.

A systemic understanding of the human body cannot be reduced to detailed knowledge of how its individual parts function, but must also include how these parts interact with each other.

The heart, therefore, is not just a muscular pump that sends oxygenated blood throughout the body; it is a much more complex organ that interacts with the brain and the other organs. The brain, in turn, continuously sends signals to the heart.

Our physical and emotional well-being depends on this complex heart-brain connection.

Giuseppe Vassalli, Cardiocentro Foundation Ticino, Lugano; Foundation for Cardiovascular Research and Education (FCRE), Lugano; Faculty of Biomedical Sciences, University of Italian-speaking Switzerland (USI); Faculty of Medicine, University of Zurich.

Inside the comic:

Matters of... the heart

Texts by the students of class 3C of the Tesserete Middle School, Ticino, Switzerland.

Illustrations by Alessandro Telve for the Scuola Romana dei Fumetti.

Repubblica e Cantone Ticino
Dipartimento dell'educazione, della cultura e dello sport