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Historical Perspectives

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Abstract

The phenomenon of yawning is just as intriguing and fascinating as sleep, yet understanding of its causes and consequences has defied the human mind for centuries. Hippocrates, Sennert, Boerhaave and de Gorter each advanced a theory in his time. From the release of tainted humor to the awakening of animal spirits and improved brain oxygenation, the metaphors that developed from these theories are all characterized by their popular success, which endured until the time of J.M. Charcot and even into our own day. However, starting in the early 19th century, a neuromuscular theory developed from the experimental physiology of Broussais and Flourens, which Dumpert (working in Germany after World War I) explained in detail. Experimental ethology and pharmacology in the 20th century brought the neuromediators and subcortical structures involved in yawning and pandiculation to light. Phylogenetically and ontogenetically primitive, these motor behaviors have been remarkably well preserved during evolution and are nearly universal in vertebrates. They are closer to an emotional stereotypy than to a reflex. Originating in the diencephalon, they appear to exteriorize homeostatic processes in the systems controlling arousal, hunger and sexuality.

Life, in all its aspects, has always given rise to thought and questioning. Explanations of physiological phenomena have always provided us with reassurance. As noted by H.L. Mencken [1]: 'Explanations exist and have always existed, because there is always a simple solution to each human problem, a clear solution that is plausible and false.' The history of knowledge on yawning is a perfect example of this precept. The causes and consequences of this intriguing phenomenon, as fascinating as sleep, have defied the human mind for centuries. The results of this review will inevitably highlight the numerous uncertainties that still exist in the 21st century.

Medicine originated in antiquity, from myth and philosophy, and gradually extracted itself from the uncertainties of magic and religion and moved towards a rational approach. This is illustrated in this chapter, which examines the development of our knowledge on yawning over several centuries.

In the tablets on Babylonian medicine that have been deciphered, there is no mention of yawning. Ethnomedicine, whether focused on Asia or Africa, has not studied yawning either.

Antiquity and the Middle Ages

Greek philosophy has provided us with a combination of 4 elements to explain the world (earth, air, fire, water). These elements carry the 4 physical qualities (moist, dry, hot, cold) that influence the 'humors' (black bile, phlegm, yellow bile, blood). These theories were applied in the first medical writings on yawning in *De flatibus liber*, a treatise on wind written by Hippocrates in 400 BC [2]. He observed:

> Yawning precedes a fever, because the large quantity of air that has accumulated ascends all at once, lifting with the action of a lever and opening the mouth; in this manner the air can exit with ease. Like the large quantities of steam that escape from cauldrons when water boils, the accumulated air in the body is violently expelled through the mouth when the body temperature rises.

As we will observe later, this idea persisted until the 17th century.

Discussing topics far removed from the physics he applied to humans, Hippocrates described jaw movement caused by yawning with great precision in *On the Articulations*, assimilating it into traumatic joint disorders. He related a reduction procedure incorrectly attributed to Nélaton in the 19th century [3]:

> With regard, then, to the matter on hand, the jaw bone is rarely dislocated, but is frequently slackened (partially displaced?) in gaping, in the same manner as many other derangements of muscles and tendons arise. Dislocation is particularly recognized by these symptoms: the lower jaw protrudes forward, there is displacement to the opposite side, the coronoid process appears more prominent than natural on the upper jaw, and the patient cannot shut his lower jaw but with difficulty. The mode of reduction which will apply in such cases is obvious: one person must secure the patient's head, and another, taking hold of the lower jaw with his fingers within and without at the chin, while the patient gapes as much as he can, first moves the lower jaw about for a time, pushing it to this side and that with the hand, and directing the patient himself to relax the jaw, to move it about, and yield as much as possible; then all of a sudden the operator must open the mouth, while he attends at the same time to three positions: for the lower jaw is to be moved from the place to which it is dislocated to its natural position; it is to be pushed backward, and along with these the jaws are to be brought together and kept shut. This is the method of reduction, and it cannot be performed in any other way.

Emile Littré [4], who translated Hippocrates' work in the middle of the 19th century, rendered a passage on the causes of apoplexy as follows:

> The continual yawning of apoplectics proves that air is the cause of apoplexy.

However, Jacques Jouanna refutes this interpretation in his recent translation:

> It is not obvious why paralyzed patients would be affected by continual yawning. There could be another explanation, namely that of patients constantly having their mouths open, which is observed in certain cases of paralysis [5]. The author, Hippocrates, has done his best to fit this observation into his explanation: the mouth stays open due to the continual presence of an excessive quantity of air in the body.

Nevertheless, modern medical observations indicate how right Littré seems to be!

Pliny the Elder noted in 40 BC that repeated yawning, when accompanied by extensive hemorrhaging, was a sign of approaching death [6]. This subject is the topic of a thesis in Latin, *De oscitatione in enixu*, written by Johannes Lapehn in 1758 under the direction of Johannes Roederer in Göttingen [7]. Hemorrhaging after delivery has killed thousands of women. The drop in blood pressure and the collapse triggered by hemorrhaging stimulates the autonomic nervous system. Yawning is an expression of this system, as it occurs during a vasovagal episode, and precedes loss of consciousness.

In his letter to Lucilius, Seneca wrote in approximately 50 AD [8]:

Just as in weakened subjects, disease is signaled by precursory signs: either excessive nervousness, or a weariness unprovoked by effort; or yawning; or a shiver running through the limbs. In this way a fragile soul is struck long before illness befalls him, suffering by anticipation and succumbing ahead of time.

Is he talking about incubation, the onset of fever, somnolence or a depressive state?

Galen and Celsus alluded to Hippocrates by transposing the productive effect of yawning winds on the muscles. Following the line of Hippocrates' observations, Oribase wrote a chapter on causes and symptoms in 450 AD [9]. He lumped together convulsions, palpitations, hiccups, trismus, limb extension and yawning:

They all belong to the same family, which involves perversion of muscular movements. […] Yawning and limb extension are acts of nature in which the body is forced to move violently by some kind of morbid cause.

In the 15th century, medical teaching began to change. Recitation of works by Hippocrates and Galen was replaced by descriptions of clinical cases and semiological ideas, spread through the invention of printing. *L'Universa Medicina* by Jean Fernel (1497–1558) is an example [10]. Fernel was the first to describe yawning as a prodrome of febrile states, calling it 'ephemeral fever'. Still influenced by the theory of humors, he described yawning as helping 'to evacuate harmful vapors'. In a similar vein, Jodocus Lommius published a collection of observations in 1560, *Medicinalium observationum libri tres*, printed in Anvers by Plantin. Translated into all European languages, this book gave rise to 30 editions over 250 years and can be compared to the modern-day *Merck Manual*. It describes yawning as a prodrome of fever [11, 12].

In 1624, Philippe Hechstetteri produced a similar collection of annotated medical observations (*Rararum Observationum Medicinalium)* [13]:

Every day at four o'clock in the afternoon, a 14-year-old girl who had not yet started menstruating experienced very frequent, very irritating yawning followed by diverse morbific accidents.

He seems to be the first person, long before J.M. Charcot, to consider repeated yawning a sign of hysteria.

Scipion Dupleix, philosopher and historiographer of Henri IV and then Louis XIII, published a wonderful collection in 1626: *La curiosité naturelle rédigée en questions selon l'ordre alphabétique* (*Natural Curiosity Compiled into an Alphabetical List of Questions*) [14]. Not without evoking *Les Propos d'Alain* (by French philosopher

Emile Chartier), on the word 'yawn' he submits the following discussion to his curious reader, so well-phrased and close to our contemporary ideas:

Why do we yawn when seeing others yawn? This is due to the common disposition of spirits or inside air, creating between us all considerable sympathy, consent and affinity, which moves and affects these spirits alike by recollection only. And for this same reason we cannot help singing when we hear others sing, our attention being otherwise occupied.

17th Century and the Birth of Research

The first half of the 17th century was marked by the birth of mathematical physics, creating a new vision of the world. A new scientific spirit was born with Descartes, resulting in the mechanistic paradigm in the field of physiology. After Galileo and Newton, the discoveries in mechanics and dynamics prepared the way for the concept of 'man as machine'. Until this period, medical dogmatism had led to a major error: an indifference towards research, as if medical knowledge were fixed and confined. After Harvey demonstrated blood circulation, the experimental approach opened the way to the quantitative analysis of vital phenomena, especially due to the work of Santorio.

Santorio Santorio (1561–1636), called Sanctorius of Padua, a physician in Venice and student and friend of Galileo, may be considered as one of the founders of experimental physiology [15, 16]. He tried to quantify physiological and pathological phenomena with measuring devices such as the scale, the thermometer and the metronome. With a scale of his own invention, he measured and compared weight gain and loss in humans, particularly by perspiration. He built an entire medical theory based on the weight differences related to nutrition, releases via the emunctories and perspiration, calling it static medicine. He mentioned yawning in his aphorisms:

Yawning and limb extension after sleep show that the body perspires abundantly, similar to the rooster that flaps its wings before it starts to sing. The urge to yawn and stretch the limbs upon waking stems from the abundance of perspirable matter, creating an inclination to perspire. Through yawning and limb extension we perspire more in one half hour than we would during other times in three hours.

In 1664, René Descartes (1596–1650) exposed his theory on nerves in his 'Traité de L'Homme' ('Treatise of man'):

The spirits that are in the brain enter into specific nerves; at the same time they carry the strength to move a specific limb. Having discussed respiration and other simple and ordinary movements of this type, I will explain how exterior objects act on the sensory organs.

Further on he explains respiration through the muscular activity of the diaphragm and focuses on 'how this machine swallows the meat at the back of its mouth …'. He concludes his complex explanation of aerodigestive tract functioning with the following:

By way of example, you can also observe how this machine can sneeze, yawn, cough, and make the necessary movements to discharge a variety of other excrements.

This demonstrates that nearly 1,000 years after Hippocrates, the evacuation of humors was still considered a primordial effect of yawning [17].

Danieli Sennerti (1572–1637) also continued to assimilate sneezing and yawning as a mechanism of 'morbific exhalation', while pointing out the coincidence with fatigue and somnolence, which had never before been noted [18].

Jan Baptiste van Helmont (1577–1644) was the first to challenge Hippocrates' ideas in *Des principes de médecine et de physique pour la guérison des maladies* ('*Principles of Medicine and Physics for Healing Diseases*') in 1671 [19]:

> Galen states that the yawning usually accompanying the onset of intermittent fever is caused by sooty vapors that swell & distend the muscles of the jaw, from which they try to detach themselves. Why are these parts of the body more excited than other parts by expulsion of this sooty matter, given that the sooty matter can only be the imperceptible excrements of the most recent digestion? And why is this matter encountered more during fever than during gout, apoplexy, etc? Why do we yawn in spite of ourselves when someone else yawns? This demonstrates that yawning does not proceed from sooty vapors, but from the imagination. The school of medicine does not contest that the orifice of the stomach is easily moved & excited to nausea by disdain for something perceived or imagined to be dirty, & that when some people watch others eat sour apples, their mouths immediately fill with saliva. Thus the upper orifice of the stomach is easily moved by the imagination, and sleep, coma, bad mood, catalepsy, drowsiness, vertigo and other accidents of this type come from the orifice of the stomach. Yawning which follows or prefigures sleep is consequently attributed to the same part of the body, because phantasy resides there and it is not without reason that we call this place the heart. It follows that when we are noticeably afflicted, we sigh repeatedly which seems to relieve this upper orifice of its oppression. When the lethargic and nonchalant stomach makes us drowsy, taking the trouble to yawn does not give any release to the muscles of the mouth and trachea which are thereby engaged. Similarly, the ethmoid bone, disturbing the organ of smell, calls on the muscles of the chest for sternutation. This does not mean that the cause of yawning should be sought in the muscles that move when one yawns, no more than the cause of sneezing should be sought in the muscles that move when one sneezes.

Calling Hippocratic Theories into Question

Herman Boerhaave (1668–1738) is considered the founder of clinical medicine and the modern academic hospital. In 1680, in *Praelectiones academicae*, he provided the first novel explanation of yawning:

> Yawning and pandiculation favor the equitable distribution of spiritus in all the muscles and unblock the vessels of which sleep may have slowed the functions [20]. In certain cases, yawning and pandiculation favor blood flow and re-establish the nervous influx; their action fights the excessive predominance of the flexor muscles and returns everything to its place. […] Yawning involves extending most of the muscles controlled by the will at almost the same time, while expanding the lungs amply and inhaling a great deal of air slowly and gradually. After the air has been held for some time and is rarefied, it is imperceptibly released by exhalation and the muscles finally return to their natural state. The effect of yawning is thus to move all the humors of the body through all the vessels, to accelerate their movement, to distribute them equally and as a result, to give the sensory organs and muscles of the body the capacity to perform their functions.

The dissertations of Johann Beutler (1685) and Gottlob Hermann (1720) build on these theories, adding a prognostic role to yawning, considered to indicate a fever's seriousness [21, 22].

Pierre Brisseau associated yawning and epilepsy for the first time in his *Traité des mouvements simpatiques* (‘*Treatise on Sympathetic Movements*’) in 1692 [23]:

The signs of an imminent attack of epilepsy are a disturbance of the soul and the senses, heaviness and pain in the head, vertigo, irritating insomnia, weariness in the joints, trembling of the limbs, ringing in the ears, yawning, heart palpitation, difficulty breathing, nausea, cardialgia, etc. All of these signs are more or less present in epileptics. […] Because blood circulates with difficulty around the lungs, yawning is easy to deduce in those about to be struck by a fit of epilepsy.

In 1733, George Cheyne (1671–1743) wrote *The English Malady: Treatise of Nervous Diseases of All Kinds* [24], in which he explains:

Yawning and pandiculation seem to be produced by hard concretions, by saline particles, by harmful vapors, bitter or acrimonious, by perspiration, by winds, etc., that are either in or stop in small vessels, or are carried to a part of the body with many nerves such as the alimentary canal, the cavities of the brain, the spine or the interstices of the muscles. Because the nerves in these places or their membranes are irritated, a general disturbance takes place in all nervous or sensible fiber, soon producing the same effect throughout the entire muscular system’. […] ‘Vapors, or splenic disorder, are commonly understood to refer to an excess of dejection, discouragement, bloating of the stomach, belching, noise in the lower abdomen, ringing or buzzing in the ears, yawning, lack of appetite, agitation, worry, anxiety, ill humor, melancholy, sadness, inconstancy, insomnia or drowsiness, or in a word all the symptoms that do not form a particular disease; but the vapors are very often symptomatic and depend on another malady.

The premises of J.M. Charcot’s ‘hystero-epilepsy’ can be found here, and it was not until the 20th century that epilepsy, cortical pathology and hysteria, the psychological condition, were separated.

18th Century: Yawning ‘Improves Brain Oxygenation’

Johannes de Gorter (1689–1762), a prolific Dutch author in all areas of medicine in the early 18th century, holds a key place in the history of knowledge on yawning. In his book *De Perspiratione insensibili* in 1755, he attributed yawning ‘to a need for faster blood circulation and to cerebral anemia’ [25]. This marks the birth of an idea that would persist for two centuries, repeated by almost all authors: yawning improves brain oxygenation.

Albrecht von Haller (1708–1777), a Swiss physician and poet, wrote the first compendium of human physiology (*Elementa physiologiae corporis humani*: 8 volumes published from 1757 to 1766). Following on from Francis Glisson, he introduced the notion of ‘irritability’, the property of tissues to be stimulated [26]. He was the first to record proof of this phenomenon and distinguished nerve impulses (sensitivity) from muscular contraction (irritability):

A kind of harmony exists between the pulse and the breath. In the natural state, there are usually three or four pulsations during one breath. If more blood reaches the heart, the number of pulsations and breaths increases. This explains why it is harder to breathe when the body is in motion, because the venous blood is whipped and accelerated. If there is greater distance in the lungs, and the blood has trouble passing from the right to the left ventricle, the number and length of breaths will be greater in order to cover the distance. This is the cause of sighs and yawning.

He goes on to describe sleep:

As night approaches, one feels a numbness in the long muscles and their tendons, together with an incapacity for serious thought and a love of rest. At this point, the forces holding up the body weaken, the eyes close, the lower jaw is left hanging, which forces one to yawn.

In the same vein as de Gorter, he advances the following:

Why do we yawn when we feel like sleeping? In order to clear the lungs in which the blood is moving more slowly.

David Hartley (1705–1757), an English physician influenced by the discoveries of Isaac Newton, attempted to explain human physiology using physical laws based on the laws of gravity. Like Hippocrates who transposed Aristotle's knowledge of nature into 4 humors, Hartley proposed that perceived sensations and voluntary acts were dependent on the vibration of particles that composed human tissue and were invisible to the eye, travelling the length of the nerves and thereby giving substance to the 'animal spirits' of Descartes. He therefore prefigured the concept of molecules [27–29]:

Depending on the circumstances, yawning and stretching may be considered part of the five classes of vibratory movements. When yawning occurs during attacks of fever and other diseases, it appears caused by sudden, strong contractions in the membranes of the mouth, throat, trachea and esophagus, whereas stretching appears caused by skin contractions.

Surprisingly, very few authors evoked yawning in animals or children. Charles Porée (1685–1770) spoke about yawning during a public session of the Académie des Belles-Lettres de Caen in 1756 where he observed [30]:

Birds yawn, just as man and several other animals do, but their yawning is different from ours. The lower part of the bird's beak is stable, whereas the upper part is mobile through a hinge connecting the bones of the bird's head to its beak. Our upper jaw is fixed, the lower jaw is mobile and moves with the temporal bones. When man yawns, the lower part of the mouth opens; while the mechanism differs, nature's intention is the same and reaches the same objective. The rest of this observation has mere curiosity value. We yawn when we are born; the first infant to be born set the example. This movement cannot be attributed to worry, as the infant knows the society he enters. Hunger and sleepiness are not the immediate cause; food will be administered through a new channel. So at first yawning has to be related to the change the infant experiences as he begins to breathe and thereafter, to the new course the blood works its way through. It can also be seen as a sign of weariness caused by the fatigue of birth and the new oscillation of the humors. All these changes are admirable and show a providence worthy of our deepest esteem. Nonetheless, one could complain that birth as well as death are difficult, and life is often less tiresome.

Joseph Raulin (1708–1784) tried to classify the nervous disorders of the ladies he treated at the court of Louis XV [31]. In his *Traité des affections vaporeuses du sexe* ('*Treatise on Vaporous Affections of the Female Sex*'), he compared spasms and convulsions and used the expression of the period – vapors – to describe what would later be known as hysteria, characterized by Paul Briquet (1796–1881) and Jean Baptiste Louyer-Villermay (1776–1838) at the beginning of the 19th century:

A woman experiences anxieties, yawning, hiccups, spasms and irregular movements in her nerves, of which she complains bitterly; her family, friends and neighbors respond with indifference. This is a case of vapors. These light vapors progress imperceptibly, the patient becomes sad, she sheds tears, or she seems cheerful, she uses expressions that are not understood, or she says pretty things, she laughs, she sings, or she alternates tears and laughter, always being beside herself. We laugh as she does, attributing this to the vapors.

History does not remember the name of Jean-Férapie Dufieu [32], yet he wrote a treatise of physiology for students, published in Lyon in 1763, in which he compiled the knowledge of his times in a literary style long forgotten in our modern manuals:

When we wake, we yawn, stretch our arms, we are more agile, our spirit is more vivacious. Since the nervous juices do not flow through the muscles during sleep, all fibers are sluggish. Thus we have to contract them all, to open the passage for the nervous juices that have filtered into the brain, or to bring them into these parts. In addition, since the movement of blood through the muscles is sluggish, its course has to be hastened; this is done by contraction where the muscles enter when the limbs are stretched. Yawning has the same cause. These nervous juices that enter into the muscles, and that have gathered up in large quantities, make us more agile, because the soul can send a large amount into the nerves to move the body parts.

This colorful description is close to many of our current concepts at the start of the 21st century!

In 1767, Achille Le Vacher de la Feutrie compiled a dictionary of surgery [33], in which he returned to the concepts of Sanctorius and de Gorter:

Imperceptibly we render a large quantity of perspirable matter when nature causes yawning and limb extension. We are more prone to yawning immediately after sleep than at other times, because a larger quantity of this perspirable matter escapes through the pores of the skin than at other times. The increase in contraction following this affluence causes the retention of perspirable matter in the passages of the skin; and that is the reason for the irritations that precede yawning and limb extension. During those movements all membranes of the body are shaken, their fibers are spread and the retained matter can escape.

Following Sydenham in England, François Boissier de Sauvages (1706–1767) [34], a famous practitioner at the University of Montpellier, tried to classify diseases using a methodology inspired by Linnaeus in the natural sciences, who generated great interest in taxonomy during that time. Boissier published a large body of work on different subject matters, but his *Nosologie Méthodique ou distribution des maladies en classes, en genres et en espèces* ('*Methodical Nosology* or *Assignment* of *Diseases* to *Classes*, *Types* and *Species*') remains his most famous work [35]:

Through the full and deep breathing that accompanies yawning, all pulmonary vesicles dilate, blood circulation in the lungs accelerates, the viscera of the lower abdomen compress, the eyes water, saliva flows abundantly, the hearing muffles, a sort of buzzing is felt inside the head, the Eustachian tube dilates, talking is impossible, perspiration increases, the soul experiences a sort of exquisite pleasure, and the person becomes more energized and more alert.

Boissier goes on to review different kinds of pathological yawning: during hemorrhages as during fevers yawning announces a fatal outcome, whereas 'stomach yawning' bears witness to indigestion and disgust. He also describes vapors accompanied by yawning, which he qualifies as hysterical.

Samuel Tissot (1728–1797) returned to practice in Lausanne after having studied in Montpellier. As a physician to prominent figures between 1750 and 1797, he was consulted all over Europe, often by correspondence. His archives contained all the medical correspondence, including prescriptions, that he conducted with his patients. His *Avis au peuple sur sa santé* ('*Notice to the General Public Concerning Their Health*') was a true early-day bestseller [35–37], translated into 12 languages and published in 17 editions. It was the first medical book written for the general public in the vernacular

language. However, above all, Tissot is the author of the first treatise on neurology, *Traité des nerfs et de leurs maladies* (*'Treatise on Nerves and Nervous Disorders'*, 1768–1770), the first volume of which is entitled *Traité de l'épilepsie* ('Treatise on epilepsy'). He attributed the transmission of information from one body part to another to a fluid circulating in the nerves that he called 'sympathies':

Such is the admirable constitution of man and animal, that those parts with seemingly different functions are however intertwined such that they all more or less influence one another […] But aside from this general harmony, there are different parts that have a more direct connection, that are linked by different means, such that the state of one has a pronounced influence on the state of another, or is at least altered by the changes that it experiences; this is due to the Greek sympathia and the Latin consensus; and sometimes the effect is much more pronounced on the part in sympathy than on the part originally affected. […] Since specific sympathies depend on nerves that have closer connections, weak causes can set them into motion; stronger causes are needed to bring about the well pronounced effects of general sympathy. All men are not equally subject to sympathies, because the nervous nature is not equally sensitive in all; hence, the same cause that brings about the most pronounced sympathies in one person, causes none in another; the corresponding action is limited to its centre, because the nerves of that person are less sensitive. It is strictly to the general consensus that we must attribute this imitative force that obliged Monro to repeat all that he saw being done. M. Whytt attributes yawning and involuntary vomiting to it; but I nonetheless do not know whether simple physical consensus is capable of generating these phenomena by itself.

Robert Whytt (1714–1766), a medical professor in Edinburgh, is known for having described tubercular meningitis. His explanation of 'sensations' (sensitivity) in involuntary movements makes him a forerunner in the area of reflexes, just as his interest in the effect of emotions during diseases makes him the father of psychosomatic pathology [38, 39]:

The different parts of our body receive from nerves not only the power to feel and move, but also a very specific sympathy that is either general and spreads out over the entire animal system, or particular, meaning that it is mainly exerted between certain parts. Whether we want to or not, we close both our eyelids every time there is a threat to one of our eyes. A sudden bright light striking our eyes sometimes causes blindness. Hippocrates observed that the sudden sight of a snake can make the face go pale. When a hungry person sees food he likes, he experiences a more abundant secretion of saliva than before having seen the object. Yawning and vomiting often occur by the simple sight or sound of someone yawning or vomiting. In this work on nervous disorders, I will mainly examine those that have the effect of a weak, delicate and unusual nervous constitution; and in this category I place the majority of symptoms that physicians have commonly described as windy, spastic, hypochondriacal, hysterical and vaporous […] Those that can suddenly be felt in the entire body or that travel through it; shivers, a feeling of coldness in certain parts as if water were being poured on them; at other times, an unusual feeling of fire […] Heart palpitations, rapidly changing pulse, most often natural, sometimes unusually slow, and other times quick or frequent, more often faint that strong, and in certain cases irregular or intermittent […] A dry cough with breathing troubles, or a convulsion or tightening of the bronchi, an accident that may come back periodically, yawning, hiccups, frequent sighing, a feeling of suffocation or constriction that seems to be caused by a lump or large object lodged in the throat, fits of crying and convulsive laughter.

Erasmus Darwin (1731–1802) is famous for being the grandfather of Charles and the author of *Zoonomia or The Laws of Organic Life* (1794) [40]. In this work, he is the first to describe the movement of a paralyzed arm in a hemiplegic during yawning:

These involuntary motions are often seen in paralytic limbs, which are at the same time completely disobedient to the will.

L'art de connaître les hommes par la physionomie (*'The Art of Understanding Men by Their Physiognomy'*, 1775–1778) by Gaspard Lavater (1741–1800) was the result of a philosophical movement dating back to Antiquity that consisted of deciphering an individual's personality from his facial features [41]. Lavater's chapter on yawning was particularly novel:

During the most passionate moments, the jaw often has an involuntary movement just as during moments when the soul is unaffected; pain, pleasure and boredom also cause yawning, but it is true that vivid yawning is a convulsion that is very prompt during pain or pleasure, whereas the yawning of boredom shows its character by the slow pace at which it occurs.

19th Century: Yawning and Hysteria

François Magendie (1783–1855) demonstrated the discoveries of Charles Bell, who distinguished the ventral roots as being motor nerves and the dorsal roots as being sensory nerves. Magendie defended his thesis on 27 March 1808: *Essai sur l'usage du voile du palais* (*'Essay on the Use of the Soft Palate'*) which included a novel chapter on yawning [42]:

Yawning, classified by physiologists among inhalation phenomena, has not been sufficiently studied in my opinion. It is generally considered a long inhalation made necessary by the slowing of the circulation upon waking, before sleep and in melancholy passions such as boredom, etc. But if we attentively examine yawning, we recognize that it is often composed of several inhalations and exhalations. At other times it occurs after inhalation, thus during exhalation. In certain rare cases we yawn without breathing in or out; this strongly suggests that yawning mainly consists in the pandiculation of the masseter, temporal and pterygoid muscles and in the prolonged contraction of the submandibular muscles. I do not completely exclude the purpose given by physiologists to yawning, but I think it must be seen as accessory. Another reason makes me persist in this idea: yawning is almost always accompanied by the pandiculation of other muscles in the body, and important muscles such as the masseter and pterygoid muscles must necessarily take part in the well-being resulting from this elongation. Do we not observe in the jaw muscles the two kinds of pandiculation seen in the trunk and the limbs? In one, the most frequent kind, we extend the limbs, we arch the trunk backwards, the flexors are elongated, the extensors contracted. In the other, the opposite happens, meaning that the trunk and the limbs are in the greatest degree of flexion possible: the extensors are elongated, the flexors are strongly contracted. We find these two kinds of pandiculation in the muscles of the lower jaw during simple yawning: the levators are elongated, the depressors contracted; in a particular state that has not yet been described, the levator muscles as well as all facial muscles enter into a violent contraction and we experience a sensation that is perfectly identical to the one felt during yawning.

Julien César Legallois (1770–1814) was a pioneer in experimental physiology. In 1813 he published his *Expériences sur les principes de la vie* (*'Experiments on the Principles of Life'*) in which he described sectioning the spinal cord of live rabbits in several locations, which allowed him to place the respiratory centers in the brainstem [43]. He reported the occurrence of yawning numerous times and considered it as a ventilatory movement:

Whatever the origin of respiratory nerves, the motive force for the respiratory function is undoubtedly in the brain. Were new proof needed, the yawning I observed after sectioning the spinal cord provides us with evidence that appears irrefutable.

Yawning clearly depends on the same motive force as spontaneous inhalation; yawning is the remains, and to some extent the vestiges of this inhalation.

Auguste Landre-Beauvais (1772–1840) created a new genre by proposing one of the first books on medical semiology: *Traité des signes des maladies* (*'Treatise on the Signs of Diseases'*, 1815). He described yawning associated with diverse pathological states [44]:

Yawning generally occurs before febrile shivering. It sometimes occurs in ataxic fevers and frequently precedes eruptions and hemorrhages. Attacks of gout, hysteria or hypochondria are often presaged by continuous yawning. Frequent yawning is sometimes observed during early pregnancy. Yawning is a phenomenon that occurs after serious injuries, excessive evacuation and internal inflammations; when accompanied by serious symptoms, it is a very worrisome sign. Frequent yawning during ataxic fevers may be considered very dangerous, particularly in connection with other phenomena that precede weakness. The same is true for yellow fever, the plague, and phlegmasia complicated by ataxic fever. Frequent yawning sometimes occurs in women during childbirth, indicating that the delivery will be difficult and that the mother's strength is oppressed or weakened. A feeling of weariness and heaviness in the limbs and less lively sensations immediately precede yawning. It is followed by increased cheerfulness and vivacity. The pulse becomes quicker and the temperature often increases. The secretion of tears and saliva is more abundant. If we relate these phenomena to what preceded the yawning – fatigue, boredom, an exterior cold – it seems that the objective of this effort is to improve the circulation in the lungs where the air flow has encountered obstacles produced by either spasm or plethora.

The first medical encyclopedic dictionary of the 19th century was managed by Charles-Louis-Fleury Panckoucke (1780–1844) and published in 60 volumes from 1812 to 1822. He solicited the great medical minds of his time such as Alibert, Pinel, Esquirol, Laënnec, Desgenettes and Larrey. This dictionary, including more than 4,000 bibliographic records and just over 200 illustrations, was an attempt to summarize the medical knowledge of the time, at the dawn of clinical medicine and anatomical pathology. The dictionary was a large commercial success, a source of wealth for its sponsor and a far-reaching vehicle for French medical thinking [45]. The entry on yawning was novel because it evoked yawning in animals and described fetal yawning, never before reported:

The Latin term for yawning comes from oscitatio; in French, bâillement is derived from the Latin balare, to bleat. Yawning consists of a large inhalation occurring slowly, and in general with wide opening of the jaws, followed by a prolonged exhalation, often accompanied by a muted noise. It is generally thought to be caused by a problem with pulmonary circulation. This opinion, while not being backed by any positive fact, does appear likely: almost all causes of yawning coincide with a certain weakness of the entire system, which could very well produce the problem we are discussing; the causes are boredom, sleepiness, fatigue, hunger, and the malaise preceding intermittent fevers, etc. Animals put into the pneumatic machine, those that are placed in non-breathable air, yawn several times before dying. A fetus taken alive from its mother's womb by caesarean operation yawns as well. Finally, it seems that damage to the pulmonary tissue can cause frequent yawning. In many cases this phenomenon seems related to the state of the stomach rather than to state of the lungs, which are only affected sympathetically; in this way, difficult digestion or a simple stomach pain, whatever the cause, is accompanied by repeated yawning. This incident can also be purely spasmodic, as observed in women affected by hysteria, or in individuals with convulsive diseases. Yawning is, to a certain extent, an involuntary act. We can overcome the action

of muscles tightening to lower the jaw by contracting their antagonists; we can moderate the exhalation that ends yawning and prevent its accompanying noise. But the long inhalation that constitutes yawning itself cannot be suppressed, undoubtedly because the agent of this inhalation, the diaphragm, receives part of its nerves from the system of ganglia, as M. Roux has noted. Bichat suspected that the object of this involuntary act is to renew the air contained in the lungs more completely than can be achieved by ordinary inhalation, and thus give way to greater absorption of oxygen.

François-Joseph Double (1776–1842), famous during his time and a founding member of the Académie de Médecine, also published a treatise on semiology and disease in 1817: *Séméiologie générale ou traité des signes et de leur valeur dans les maladies* [46]. In his work, he summarized the same findings as Landre-Beauvais:

A rapid consideration of the mechanism of yawning clearly suggests its degree of influence on the system. Its importance cannot be denied if we think about the general state that precedes and follows it, for example, the kind of stupor and torpor that prepares the way and the weariness and weakness we feel beforehand, in contrast to the pleasant sensation that follows and the relaxation and well-being it procures. By reflecting on these diverse subjects, we find the indication for most of the signs that experience has attached to yawning. […] Pandiculation consists of successive stretching of all muscles accompanied by a pleasant sensation and generally followed by yawning. […] Pandiculation is a very positive sign leading into convalescence, but if it continues and persists relentlessly, it indicates a deterioration. During the course of a disease, pandiculation is always salutary; it signals the favorable state of the vital forces and the resistance with which nature fights the effect of the disease.

During the same period, at the age of 22 years, Anthelme Richerand (1779–1840), known for his quarrels with Dupuytren, published *Nouveaux éléments de physiologie* (‘*New Elements of Physiology*’) [47]. This important compilation of writings from the period lacked originality but possessed a style that made it a highly successful teaching tool, as this account confirms:

This work brought charm and beauty to our school years. It was a delightful introduction to the austere study of medicine; the reading could be considered light, but it seemed to sprinkle the subject’s first paths with flowers.

The article on yawning demonstrates this:

We also yawn upon waking, in order to lift the thorax muscles to an appropriate degree for respiration, which is always slower, less frequent and deeper during sleep than during the waking state. Due to a similar need, waking in all animals is marked by pandiculation, a muscular action in which the muscles seem to accommodate the contractions that the movements dictate. The crowing of the cock and the agitation of its wings serve the same purpose. Finally, the same necessity leads the numerous flocks of birds that inhabit our woods to warble endlessly at sunrise and fill the air with harmonious song, in which the poet hears the joyous hymn by which the feathered populace celebrates the return of the god of light!

Nicolas Adelon (1782–1862) was the author of a long article devoted to yawning in the *Dictionnaire de Médecine* published from 1829 to 1836 [48]. He expanded on the respiratory theory of yawning, helping to ensure its 150 years of success:

In the state of health, yawning occurs in a vacuum, in a situation where there is no renewal of fresh air, because in these cases there is not enough air, or the air contains less oxygen, and we try to compensate by introducing a large amount of air to where it is lacking. This is why yawning is a precursory phenomenon of all gradual asphyxiations. We yawn when sleep approaches, because the momentary paralysis that seizes all muscles in the body also seems to seize the respiratory

muscles, which results in a temporary decrease in the frequency of inhalation. Since the circulation has continued in the meantime, and as a result has carried the same quantity of venous blood to the lungs to be transformed into arterial blood, there is not enough air to perform this conversion, and a small amount of venous blood remains in the lungs, slightly blocking pulmonary circulation: yawning thus occurs automatically to introduce a larger quantity of air, the quantity needed to arterialize the leftover venous blood and restore balance. Yawning occurs in all circumstances where we see this accumulation of venous blood in the lungs, this blockage of pulmonary circulation. It is thus considered a physiological remedy for dissipating this engorgement, and its full accomplishment is followed by a sensation of well-being. Judging from this feeling, the outside air introduced into the lungs by yawning could be considered to overcome the obstacle blocking the circulation in these organs. We also yawn during the first moments of waking, because inhalation occurs in a different mode than during sleep, and in the passage from one mode to the other, there is a momentary decrease in inhalation, due to an imbalance in the amount of air introduced and the quantity of venous blood to be transformed into arterial blood. The result is a slight pulmonary engorgement, leading to the phenomenon necessary clear it.

During the same period, John M. Good (1764–1827) explained yawning and pandiculation in *The Study of Medicine with a Physiological System of Nosology* in England [49]. Taking a very different approach from his contemporaries on the continent, he never evoked the ventilatory mechanism, but saw yawning as simple muscular work necessary for the balance between extensors and flexors. These notions come close to modern-day physiological observations.

In 1861, Adolphe Dureau de la Malle (1777–1851) published a dissertation on the development of intellectual faculties in wild and domesticated animals in the *Annales de Sciences Naturelles* [50]. He reported having such close ties to his dog that the latter started yawning when he saw his master yawn! Present day authors Joly-Mascheroni and Senju published a study in 2008 that comes to similar conclusions [51].

François Broussais (1772–1838) broke away entirely from his contemporaries and predecessors in his *Traité de physiologie appliqué à la pathologie* (*'Treatise on Physiology Applied to Pathology'*), published in 1834 [52]:

If we wish to study the mechanism of yawning, which can be considered as the first sign and main phenomenon of boredom, either moral or physical, we will encounter serious problems. Yawning has been related to the need to breathe, or considered a means to renew the air stagnating in the lungs after respiration has slowed for some time. This is an error – one must only be a practitioner to know with certainty that dyspnea alone never produces yawning. […] The lungs seem to be much less influenced by yawning than the stomach … [If] the need for air is not the principal cause of this deep aspiration, then what can its purpose be? Could it be to swallow air, and to cure an ill stomach?

This novel approach did not generate much response and the ventilatory theory persisted.

John Abercrombie (1780–1844), a Scottish physician, published *Pathological and Practical Researches on the Diseases of the Brain and Spinal Cord* in 1828 [53], which was translated into French in 1832. He described the strange phenomenon encountered in certain hemiplegics where the paralyzed arm moves up towards the mouth simultaneous to yawning. This occurrence disappeared as soon as the paralysis subsided.

In 1842, Pierre-Marie Flourens (1794–1867) gave a clear explanation of motor automatisms and their coordination – Recherches expérimentales sur les propriétés et les fonctions du système nerveux dans les animaux vertébrés (‘*Experimental Research on Nervous System Functioning in Vertebrates*’) [54]:

The spinal cord is restricted to linking muscular contractions, the first elements of all movement, into complex movements. Although the spinal cord is the point of departure for almost all nerves determining these contractions and movements, it is not the seat of the admirable power to coordinate them into specific movements: jumping, flying, walking, running, resting, etc.; or inhaling, shouting, yawning, etc. This power resides in the cerebellum for the first group, in the spinal bulb for the second group. There is one last consideration to note. The movements of respiration, shouting, yawning, etc., are commonly called involuntary, whereas locomotive movements are called voluntary.

Louis Delasiauve (1804–1893) and Théodore Herpin (1799–1865) are associated with the detailed description of the different types of epilepsy, which include generalized and partial seizures. They described prodromes warning the patient of an imminent seizure, notably repeated yawning. These symptoms are currently attributed to partial temporal seizures [55–57].

End of the 19th Century: Is Yawning a Reflex?

Jean-Louis Brachet (1789–1858), an eminent physiologist in Lyon, was the first to contest the respiratory role of yawning [58]:

Yawning is generally defined as a large, deep inhalation occurring slowly that moves the lower jaw, the hyoid bone and the larynx considerably downward. It is followed by a prolonged exhalation accompanied by a particular muted noise. Yawning is attributed to the need to renew air in the lungs, or to introduce a larger quantity of air to supply the blood with more oxygen, because the flow is blocked and oxygen is consequently lacking. Or yawning is attributed to a feeling of malaise arising in the back of the throat, in the upper part of the neck. We do not share this view. We do not consider the phenomenon to be limited to this convulsive contraction of the facial and neck muscles, nor to this larger volume of air that it sends through the airways. Yawning is not a purely local phenomenon pertaining exclusively to respiration: it is a general phenomenon pertaining to the complete system. […] We therefore think yawning, as well as pandiculation, occurs when the brain, alerted by the torpor seizing the system, tries to prevent the consequences by soliciting acts of excitation and arousal; thus all muscles contract, the locomotive as well as the respiratory muscles. This general contraction is already a means of stimulation.

Almire Lepelletier de la Sarthe (1790–1880), a proponent of physiognomy which Johann-Casper Lavater developed in 1775, largely surpassed his master with his reprehensible words [59–61]:

When yawning is customary, we can assume the following about the subject: limited intelligence, without initiative, slow and lazy mind, inactive, soft character, weak, indolent, timid, indifferent, melancholic, boring, incapable of vigorous resolution or undertaking a long, difficult or perilous enterprise, at times clever and cunning, and given to contemplating theft and fraud in his dealings.

In 1865, Jules-Bernard Luys (1828–1897) published *Recherches sur le système nerveux cérébro-spinal, sa structure, ses fonctions et ses maladies* (Studies on the Cerebrospinal Nervous System, Its Structure, Functions and Diseases’ [62]). He

described the central grey nuclei, giving his name to one of them, and postulated on their physiological role, which had never been studied before his time. He developed novel ideas concerning yawning as well:

> Although not extensively discussed, it is a common observation that when the brain cells start to become inactive, the medullary regions of the spinal axis with immediate control over the respiratory apparatus are altered in their functioning. Everyone knows that yawning is a premonitory sign that the conditions of diurnal functional activity in the nervous system have ceased to be what they previously were. What is yawning if not an involuntary inhalation indicating that the innervation of automatic activity acquires a predominate influence in the medullary region, following retrocession of the cerebral influx, and that at this precise point of the spinal axis, a sort of interregnum occurs and a disturbance of the original stimulus. In addition, the highly characteristic rhythm of the respiratory movements during the period of brain collapse, their well-measured succession and their overtly automatic nature lead us to believe that they are no longer controlled by the same centres of innervation that supply them during the waking state.

We have now reached the end of the 19th century, which was dominated by the work of Jean-Martin Charcot (1825–1893) and his students Charles Féré (1852–1907) and Georges Gilles de la Tourette (1857–1904). The most famous observation of pathological yawning was presented by J.M. Charcot on Tuesday, 23 October 1888 [63]. His young 17-year-old patient yawned 8 times per minute, or 480 times per hour, only interrupted by sleep; she had generalized epileptic seizures, complete anosmia and binasal hemianopsia. Reporting this observation in the *La Nouvelle Iconographie de la Salpêtrière* in 1890, Gilles de la Tourette specified that she had been amenorrheic for nearly a year, but he did not indicate whether she was examined for galactorrhea. And yet J.M. Charcot noted: 'After what I have told you, you have undoubtedly surmised that we are in the domain of hysteria.' If we may criticize the master 120 years later, J.M. Charcot's young patient was most likely suffering from a prolactinoma compressing her optic chiasma and her hypothalamus. Surprisingly, J.M. Charcot continues his discussion without evoking any criticism:

> Physiologically we affirm that this is an automatic act, required by a certain degree of anoxemia, a need for oxygenation of the nervous centers.

In the third volume of *La Nouvelle Iconographie de la Salpêtrière* (1890), Gilles de la Tourette added four other observations involving abnormal movements and convulsions attributed to hysteria [64]. It is difficult to establish an exact diagnosis, but an organic pathology involving the thalamus or hypothalamus seems probable, such as a tumor with intracranial hypertension or a chronic tic disorder. In 1895, Gilles de la Tourette reviewed and commented on these cases again in his *Traité de l'hystérie en trois volumes* (*'Treatise of Hysteria in Three Volumes'*), justifying what he believed to be their hysterical origin [65]. Lastly, in 1905, Féré published a report on yawning to the Société de Biologie that describes his efforts to measure muscular force, observing its decrease after yawning [66].

Paolo Mantegazza [67] (1831–1910) was an Italian psychologist and author of *La physionomie et l'expression des sentiments* (*'Facial Characteristics and the Expression of Sentiment'*). He was the first to report:

Yawning expresses a wide variety of things, such as hunger, thirst and, especially in women, the need for physical love; but in the expression of pain it is a characteristic element of boredom.

In 1891, Henrietta Russell, an American from New York, published a book called *Yawning* [68]. In this, she described natural gymnastics, comparable to contemporary relaxation, and explained the benefits of yawning, which results from relaxation and produces a feeling of release and well-being. She has since gained a following, and a thesis was dedicated to this topic in 2006 in France.

20th Century

The year 1901 is key in the study of yawning. René Trautmann (1875–1956) defended his doctoral thesis – *Le bâillement* – in Bordeaux under the direction of Paul Vergely [69]. It is the first of three dissertations on this topic presented in France during the 20th century, and by far the most interesting. Trautmann, educated in a military medical school, spent his entire military career as a physician in Africa. He produced ethnological studies that were marked by the colonizing spirit of the period, in addition to a few short stories based on his travels. His thesis presents a very rich historical perspective and one that is still very useful. Trautmann described the activation of the facial muscles and respiratory channels in detail, as none of his predecessors had, and concluded that yawning improves blood oxygenation. He reviewed the different theories explaining the contagiousness of yawning and proposed that:

Yawning falls into the category of occurrences reinforced by habit and favored by moral depression. When the mind concentrates, when we are very attentively listening to a story, we do not yawn, even if one or more people engage in this act. Yawning is a purely imitative phenomenon, as are the gestures and involuntary facial movements executed by many individuals attending a speech or declamation. Depending on the subject, more frequent yawning is the result of a greater tendency towards instinctive imitation.

Trautmann accepted the idea that yawning is involuntary but challenged the historical writings he cited by proposing a method to trigger yawning at will:

[For] some time we have observed that we can willfully effectuate complete yawning by means of a particular mechanism; several of our colleagues, who are medical students, have reached the same conclusion. One need only tighten the subhyoid muscles vigorously while inhaling slowly and profoundly. The lower jaw is dropped down and pushed forward, and there is a buzzing in the ears: yawning takes place.

Trautmann thoroughly reviewed all forms of pathological yawning and added personal observations of a rapid succession of yawns during shivering at the onset of fever. A long chapter describes yawning in pregnant women, especially during puerperal fever or delivery accompanied by hemorrhaging. It is completed by Trautmann's own observations. In his conclusion, he writes:

While yawning always occurs in the same manner, it can be considered – as a muscular act and depending on the case in which it occurs – as a particular type of reflex: (a) an exclusively spinal reflex, (b) a mesencephalic reflex or (c) a cerebral and cortical reflex.

At the end of his thesis, Trautmann challenges the ventilatory theory, which does not explain all the clinical cases he presents, and his work suggests the existence of neurological mechanisms that trigger yawning. Trautmann thus appears to be the first modern-day thinker on yawning.

In 1905, André Vigouroux and Paul Juquelier wrote a book entitled *La contagion mentale* (‘*Mental Contagion*’) [70]. They saw yawning as a reflex, which made it contagious by nature. In particular, they developed a hypothesis that became successful under the term ‘théorie de l’esprit’ (mind theory). It stated that by involuntarily mimicking the gestures, actions and emotions of others, we acquire the ability to decode the feelings of the person we observe. Interest in this theory was renewed with the discovery of mirror neurons at the end of the 20th century [71]:

> [The] sight of coordinated, rhythmic actions that have become reflexes for those who perform them, provokes in onlookers motor reactions that are perfectly involuntary but also rhythmic and that represent a rough reproduction of the perceived acts.

In 1916, F.H. Pike from Columbia University in New York proposed a comprehensive review in the *Journal of Heredity*. Taking account of animals and human fetuses, Pike rethought the origin of yawning, discussing both the influence of hunger and the need to fight an enemy [72].

In *The Lancet* (21 January 1905), John Hughlings Jackson described a personal observation. While performing a funduscopy on a patient, he suddenly observed a retinal paleness attributed to an arteriolar spasm that was quickly followed by yawning, which restored the appearance of the retina [73].

The period following World War I was marked by a significant epidemic of encephalitis lethargica, also called von Economo disease [74]. In addition to the lethargic forms that were often fatal, or the curable forms that left the patient with Parkinson’s disease and abnormal movements (oculogyric crises), a rarer form of encephalitis manifested itself through stubborn and fatal insomnia, very often accompanied by a rapid succession of yawns. In 1921, Jean Sicard and André Paraff published a case associated with uncontrollable laughter, comparable to gelastic epilepsy [75]. In 1922, Gabrielle Lévy, a student of Pierre Marie and Jean Lhermitte dedicated her thesis to this topic in France [76]. At the same time, Arthur Hall in England [77], Smith E. Jelliffe in the USA [78], Raymond de Saussure in Switzerland [79], and Georges Guillain and Pierre Mollaret in Paris [80] all collected observations in which yawning can be interpreted as abnormal movement, similar to tics and relaxation behavior at the end of involuntary episodes of hyperventilation.

Edouard Claparède (1873–1940) was a Genevan physician and psychologist. One of his specialties was child psychology. In a journal for teachers entitled *L’Educateur*, he published an article in 1924 [81] that drew on the work of the German Valentin Dumpert in 1921 [82]. He noted that yawning results from a massive contraction of the diaphragm and is part of pandiculation, rather than being directly tied to breathing. He was the first to overturn the paradigm of ventilatory yawning, pioneering today’s neuromuscular theory in which yawning has a diencephalic origin:

Yawning is only incomprehensible when considered alone. On the contrary, it becomes clearer if we see it as part of a more general reflex, the reflex of stretching. It is well known that yawning hardly ever occurs without general stretching of the body. This is striking in certain animals, such as dogs or cats. It is also evident in small infants, and very often in adults.

Through self-observation, Dumpert noted that voluntary stretching activates yawning (this is easy to reproduce). He also observed that yawning evokes associated movements in hemiplegics; they present extension in their paralyzed limbs that lasts throughout the yawn. Claparède was convinced that these associated movements were part of the stretching reflex: 'When one of our listeners yawns, can we assume he is tired of listening to us, when on the contrary, he may be doing his best to keep listening?'. Yawning thus became a means of stimulating vigilance, a true revolution!

In 1937 Paul Delmas-Marsallet presented an article entitled 'Le signe du bâillement dans les lésions du cerveau frontal' ('Yawning in frontal brain damage') in the journal *Oto-Neuro-Ophtalmologie* [83]. He described five observations of uncontrollable yawning resulting from either frontal hematomas or frontal tumors. He proposed that uncontrollable yawning was a clinical sign of intercranial hypertension, which remains true.

In 1946, Paul Heusner published the first summary article in English in *Physiological Review*. Phylogenesis emerged for the first time [84]. Heusner precisely described different durations and scientifically measured daily timescales. He proposed that the brainstem and basal ganglia were responsible for yawning, based on yawning in anencephalic newborns and in hemiplegics during brachial parakinesis.

In 1958, Jean Barbizet published a large compilation of data and historical information in French and English [85], together with the first radioscopic measurements, which he had taken, of pharyngolaryngeal expansion during yawning. He thus showed that during the culmination of yawning, pharyngolaryngeal diameter is multiplied by four. He also described the first works of P. Passouant, who triggered experimental yawning in cats by electrostimulation of the hypothalamus. In addition to mentioning involuntary parakinesis in the paralyzed arm of a hemiplegic, he reported the unusual observation of D. Furtado, in which passive movement in the paralyzed arm of a polio patient triggered yawning, which has never been reported since [86].

In 1962, A. Montagu wrote an article in the *JAMA* that has since been frequently quoted. He proposed that yawning stimulated vigilance, while attributing lowered vigilance to insufficient brain oxygenation [87].

J. Boudouresque attempted to summarize knowledge on yawning for the *Encyclopédie Médico-Chirurgicale* in 1965 [88]. Returning to the old concept of yawning as a modified respiratory act, he clearly identified it as originating in the diencephalon and the brainstem. After cataloguing all the causes of excessive yawning, he concluded: 'Yawning is the most suggestive sign of mesodiencephalic distress. It has considerable prognostic value as a synonym of gravity.'

The age of pharmacology began in 1963 with publications on the experimental activation of yawning, always associated with erection and often with stretching of the limbs

in rats, cats and mangabey monkeys. In the *Annals of the New York Academic of Sciences*, Ferrari et al. [89] published the results of intracerebral injection of ACTH, a pituitary hormone stimulating the secretion of cortisol and other adrenocorticoids. ACTH, a peptide with 41 amino acids, is produced from a precursor (proopiomelanocortin) and acts on the paraventricular nucleus of the hypothalamus; however, proopiomelanocortin is also the precursor of other hormones, such as α-MSH (which stimulates melanogenesis). These hormones were shown to activate yawning after cortical injection [89].

The central role of the paraventricular nucleus in the hypothalamus was identified in 1980 by the work of W. Ferrari, A. Argiolas, and M.R. Melis in Italy, as well as R. Urba-Holmgren and B. Holmgren in Mexico [90]. This transformed the approach to the dopaminergic and cholinergic systems in the brain.

During the 1980s and 1990s, American psychologists R. Provine and R. Baenninger published the first scientific work on the behavioral study of yawning, based on observations of their students [91, 92]. Ethnologists B.L. Deputte in France [93] and F. Troisi in the Netherlands [94], working with no apparent connection or consultation, described different types of yawning in non-human primates, notably testosterone-dependent yawning in dominant males.

Today, at the start of the 21st century, the neurohormonal mechanisms appear to be established, making yawning a marker of activity in D_3 dopamine receptors. The study of 'contagious' yawning offers an example of non-verbal language that is part of the theory of mind. Observations such as the lack of yawning in autistic children together with brain imaging studies are changing the neuropsychological approach to involuntary decoding of emotions, bringing yawning closer to empathy.

Having been associated with forced ventilation for centuries, yawning has become an emotional stereotypy exteriorizing homeostatic phenomena in the systems controlling arousal, hunger and sexuality.

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