Bruno Krüger • Sours-Allee 3a • 55276 Dienheim • Germany

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Evolutionary Step to Bilateral Symmetry

⇒ This article deals with a basic mechanism that contributes to the understanding of higher life forms based on bilaterally symmetrical body shape. The striking evolutionary step that took place in a short time is considered with a functional concept to explain it.

The evolutionary step towards bilaterally symmetrical body shapes took place in proximity to the emergence of central nervous systems and the blood circulation. The starting point for the relationship formulated in this article is the cell cycle during cell division that is stepwisely controlled by proteins. Controlled and, as a result, symmetrical growth could be made possible by axonal transport of proteins via nerve fibers. The core of the mechanism discussed is a body-side-bridging cycle for protein transport. A pumping effect is generated via agonist-antagonist-organ pairs and the direction of circulation is determined via nerve stimuli.

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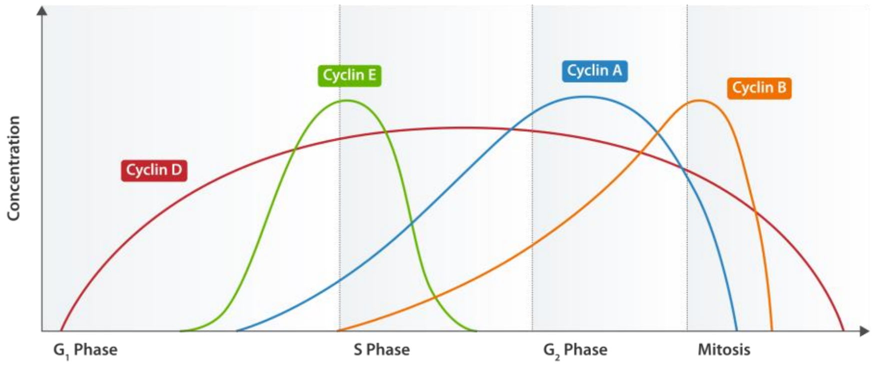
Starting point

Living things are self-organizing, complex structures. Is it perhaps only their finished form that makes the complexity appear so impenetrable? Evolution is driven by chance. According to the laws of probability, less likely coincidences are to be expected for long periods. This leads to striking evolutionary steps. The idea now is that the enormous complexity of bilaterally symmetrical body shapes arises from a multitude of subsequent developments. In the beginning, however, there is a single basic mechanism, the implementation of which does not require very many coincidences in one step. Multiple and, above all, simultaneous coincidences would mean that a finished living being could fall from the sky to a certain extent. In the following, the mechanism discussed is first presented with a functional scheme suitable for bilaterally symmetrical organisms. Connections with evolutionary steps that were sometimes necessary before bilateral symmetry are shown. After that, connections and characteristics are collected, which can be classified in accordance with the symmetry mechanism.

Modular system kit of evolution

The mechanism presented in this article is based on a series of known functions and properties, which will be briefly listed as follows for later understanding of the relationships. To a certain extent, this is part of the kit that is available to evolution and with the help of which a basic mechanism can be reconstructed. It must be clear that there is still much to be researched in detail in respect to function, occurrence in evolution and exact sequence in the growth of living beings. The relevant principles connected to the properties are important.

Principle	Functions and properties in the modular system of evolution
Stepwise controlled cell division	Cyclins are proteins that are found in all eukaryotes and are involved in regulating the cell cycle. Characteristic cycline concentrations are observed at different phases of the cell cycle.  Source: www.spektrum.de, www.wikipedia.de
Transport route via nerve fibers	Fast axonal transport is carrying mainly vesicles, roundish units that are moved by motor proteins at speeds of 25 to 40 centimeters per day. The transport can take place downstream in the direction of the synapse, or in the reverse orientation from the synapse in the direction of Soma. Source: www.wikipedia.de
Nerve stimuli to the muscles through motor neurons	The upper motor neuron is responsible for deliberately triggering the movement. Its cell bodies, the Betz giant cells, lie in the motor cortex in the cerebrum. The axons or nerve fibers form the pyramid path. They never pull directly to the muscles, but always to the lower motor neuron in the spinal cord. The lower motor neuron ignites the actual stimulus for the muscles. Its cell body lies in the anterior horn, also: ventral horn, of the gray matter of the spinal cord. Source: www.wikipedia.de
Muscle pairing that interacts during movement	The antagonist is a muscle and opponent of the agonist. The muscular interplay of limbs of the body is also referred to as the opponent principle. The classic anatomy assumes that this principle can be described using the example of the flexor and extensor muscles on the arm as follows: If the biceps is actively shortened when the arm is bent, the triceps is passively stretched. Source: www.wikipedia.de
Agonist and antagonist on the other side of the body can be	Flexion reflex when stepping on a thumbtack: the flexor on one side of the body is excited and the extensor inhibited via interneurons in the spinal cord. At the same time, the extensor on the opposite side is also excited via interneurons and the flexor is inhibited - crossed stretching

addressed via connected stimuli	reflex. If one leg is pulled up because of pain, the other is stretched and can now carry the body weight. The flexion reflex thus serves as protection against harmful stimuli and is also referred to as a nociceptive protection reflex. Source: http://www.herzinger-wolfgang.de
Bilateral symmetry from the cotyledon development	Embryonic development describes the development steps through the cotyledon development and the emergence of the neural tube, from which the central nervous system with the spinal cord and brain emerges. Even at an early stage, the so-called primitive channel forms on the epiblast, which divides the new life into two symmetrical areas. Source: www.amboss.com
The central channel continues the symmetry created with the cotyledon	The central channel is a narrow channel centrally located in the spinal cord that contains brain-spinal cord fluid. It extends the entire length of the spinal cord and continues into the elongated marrow of the brain. The central channel emerges from the lumen of the embryonic neural tube. Its narrow fluid-carrying cavity is connected to the internal cavities of the brain. Source: www.wikipedia.de
Lower motor neurons are only found in the abdominal or ventral area of the spinal cord	The sonic hedgehog protein, in short: Shh, a glycoprotein secreted by the chord process and later by the neural plate, suppresses genes which is responsible for the formation of the dorso-ventral polarity. This means the division of the spinal cord into a part specializing in sensory functions and a part specialized in motor functions. The differentiation of motor neurons in the ventral spinal cord oriented towards the abdomen is made possible. Source: http://www.embryology.ch

Continuation and detailing would be possible. Therefore, this listing should be regarded as a bridge to the state of the art and as a possible starting point for studies independent of this article. Its purpose is to set out relevant and already scientifically verified principles on which the following considerations are based upon.

Synchronization of partner organs on both sides of the body

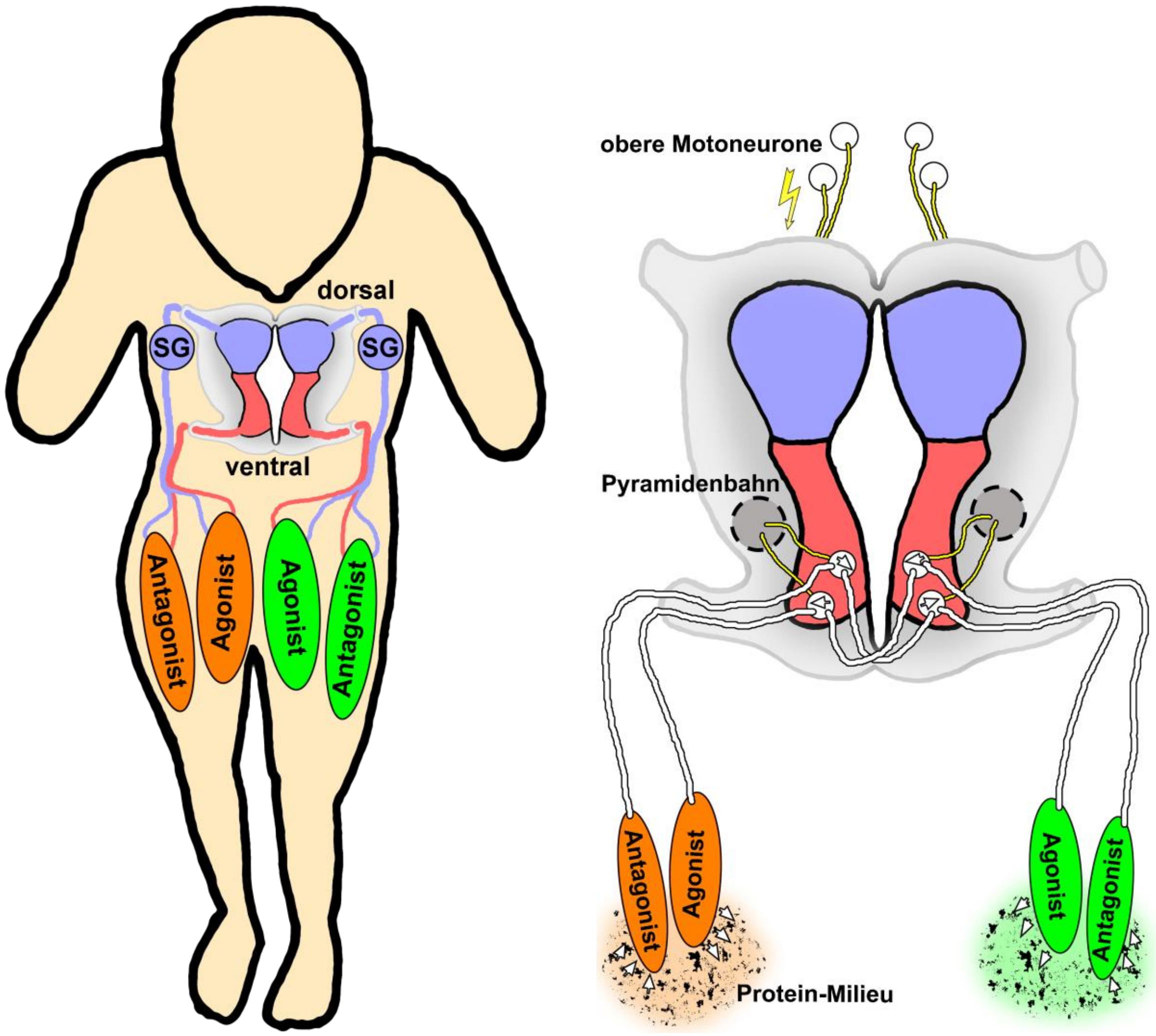
Life develops its shape through growth and cell division. The following thesis for the mechanism behind bilaterally symmetrical body shapes shall start the concept: The same organs based on the same cell types, which later appear in pairs on the left and right side of the body, must control their respective cell cycles. The separated locations of the paired organs require extensive signal transmission throughout the entire body.

The essence of the matter is self-organized control. This succeeds with the idea of a role of controlling and one of being controlled in cell division. The left and right partner organs or muscles assume both roles in the interplay. The function of control is mediated by proteins. Even before bilateral symmetry, evolution had developed a phase-controlled cell cycle in whose rhythm entire bundles of cells divide synchronously. Only when the maturity for entering a new phase is reached is the production of suitable cyclin proteins observed, which accompany the start of the phase.

Assumption for the mechanism for bilateral symmetry: The growth of a partner organ stagnates when it is decoupled from its partner-induced protein supply. With the evolution step, the inhibition of a certain cyclin required for the start of a cell cycle phase comes into play more when an appropriate cyclin is supplied to an organ from the outside. It is assumed that this provision is made by the contralateral partner organ. As a result, symmetric and possibly more efficient growth can be expected.

The transport routes via nerve fibers would have a suitable speed for the synchronization of the partner organs on both sides of the body, so that cell cycle phases with a larger organism could be expected in the range of days. A partner organ that was at times smaller in the symmetrical development would correspondingly produce fewer cyclin proteins for the control and thus fewer cells of its partner would enable cell division. The proportions of the cells supported in their division-proceeding would automatically self-regulate on both sides of the body.

Mechanism for enforcing bilateral symmetry



Depiction: Mechanism for the evolutionary step towards bilateral symmetry

Crosswise coupling of agonists and antagonists on both sides of the body:
We know that the lower motor neuron for the agonist on one side of the body and the motor neuron for the corresponding antagonist on the other side of the body can be addressed simultaneously via stimuli connected to one another in the spinal cord. We believe that there

are direct links from the left to the right side of the spinal cord that also allow protein transport and cross-link agonists and opposing antagonists.

Contraction effect of the organs:
We know that nerve fibers that pull out of the spinal cord reach agonists and antagonists and can supply them with proteins as well as with electrical stimuli. Proteins can also be transported back towards the spinal cord. We assume that the attached organs produce a pumping effect by contraction through electrical stimuli. This effect can either transport proteins from the nerve fiber into the organ or alternatively proteins from the environment of the organ into the nerve fiber in the direction of the spinal cord. A mechanically driven circuit can form.

Upper motor neurons control agonist and antagonist:
We know that the upper motor neurons have a clear and direct connection at distances of up to one meter to their respective lower motor neurons, so that each agonist and each antagonist is addressed individually starting from the cerebrum.

We assume that upper motor neurons send out stimuli to an agonist-antagonist pair that are related in time, but do not arrive at the same time due to the interconnection of the upper motor neurons. We further assume that with the emergence of the mechanism it is determined which outgoing nerve fiber always conducts the first electrical stimulus. This would define the agonist as such. Contractions and pumping effects would be triggered in the order, first agonist - then antagonist.

A mechanically driven protein cycle is created when the agonist begins to pump, through which proteins from its nerve fiber enter the environment of the organ and briefly create an overpressure there. The delayed pumping action of the antagonist would be influenced by the surrounding overpressure in the early phase of development and would direct the transport of proteins towards its nerve fiber. As a result, the sequence of nerve stimuli would lead to the closing of the protein cycle and to a tightening of its direction of rotation.

Scientific relevance

The bilaterally symmetrical body shape in higher life forms is an obvious conspicuous. As suggested in the previous sections, this can be contrasted with a possible functional diagram. The scientific value lies in the systematization of observations and their classification in an overall context. Think, for example, of genetics, with the help of which living beings can be classified via statistical analysis in a family tree. The knowledge of contexts makes a fundamental contribution to subsequent research and opens new, promising ways of thinking.

It will be difficult to precisely trace the formation of bilaterally symmetrical body shapes. The functional scheme proposed in this article is very simplified and there is an enormous variety of confirmed medical and neurophysiological findings. On closer inspection, these are likely to lead to necessary corrections to the proposed functional diagram.

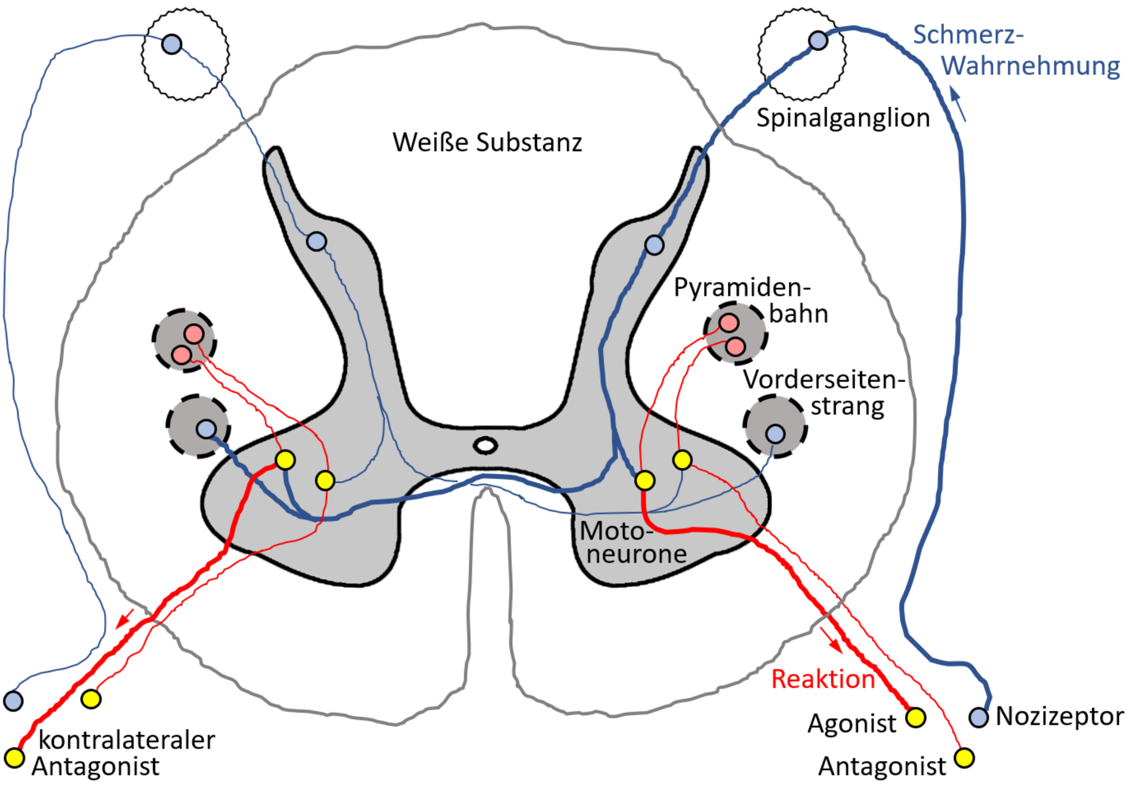
A cross-section of the spinal cord is shown in the picture above for the mechanism for the evolutionary step towards bilateral symmetry. The illustration shows the spinal cord in a middle phase of embryonic development. According to the current state of knowledge, it is difficult to decide which areas of science contribute best to an explanation. Embryonic development is about the sequence in the formation of neuronal cells, their cell differentiation and the segmental migration of mesoderm cells. In neurophysiology, on the other hand, there is enormous knowledge of functional details, such as reflexes. This gives a view of the neuronal connection in the spinal cord.

The functional diagram shown above could then if necessary be expanded with sensory nerve stimuli. This would address the question of the context in which the connection between motor neurons start bridging the body. A distinction is made between reflexes triggered by sensors, i.e. not by willpower:

- Monosynaptic self-reflexes:
  These are self-reflexes that serve to stabilize the body; ascending nerve stimuli, so-called afferents from one muscle establish contacts with motor neurons of the same muscle in the spinal cord; Striking with a reflex hammer leads to muscle twitching;

- External reflexes:
  Interneurons are interposed between afferents and descending motor nerve stimuli, so-called efferences; these are used for body protection, eyelid reflexes, escape reflexes, etc .; Flexor reflex: painful irritation leads to the affected limb being pulled away by articulation, e.g. Sole reflex, ipsilateral extensors are inhibited at the same time.

Source: http://stud.neuro-physiol.med.uni-goettingen.de, script for the summer semester 2016



Depiction: Mechanism for bilateral symmetry expanded by sensory interconnection

The front strand (in German: Vorderseitenstrang) shown in the picture contains the so-called tractus spinothalamicus lateralis, an ascending fibrous web in the lateral spinal cord. Its fibers primarily conduct protopathic sensations - pain, temperature - to the thalamus. The lines in bold type show the signal path when an external reflex occurs, which agonist and matching antagonist muscle of the other side of the body respond in combination. A chain of sequentially connected neurons has been scientifically proven:

1. Neuron in a spinal ganglion before entering the spinal cord,
2. Neuron in a dorsal horn of the spinal cord,
3. Neuron in the ventral posterolateral nucleus in the contralateral thalamus in the brain.

Sources: www.wikipedia.de, Lemniskales System and https://flexikon.doccheck.com, Tractus spinothalamicus lateralis

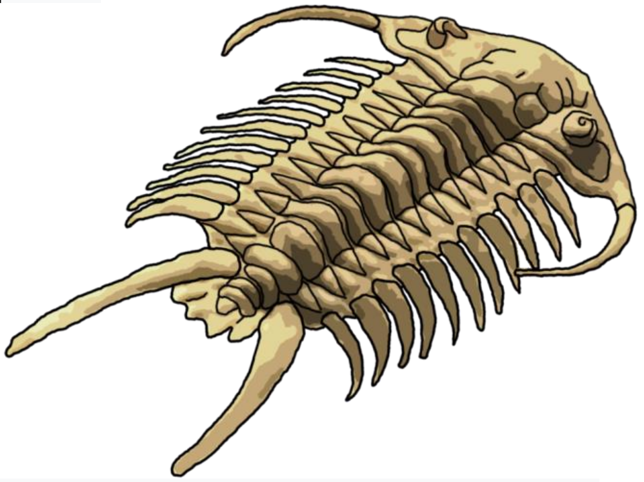
The scripts of neurophysiology describe further and far more complex neuronal circuits that affect motor neurons. The reflex selected here for extension appears to be relevant for an explanation of the symmetry mechanism for several reasons. It transports pain to body protection and should have played a role in early evolution. The neuron involved in the posterior horn acts directly on the motor neurons without any additional neurons in between. The interconnection in this simplicity seems more likely to occur early in evolution.

On the way of the nerve fiber from the second neuron in the dorsal horn via a switch to the contralateral side to the thalamus in the brain, secondary branches of the fiber, so-called collaterals, branch off. These act on one side of the body on the motor neuron of an agonist and on the other on the suitable motor neuron for the corresponding antagonist. With and between the collaterals, the connection is created which becomes part of the transport route and forms the bridge for the proposed protein cycle from left to right.

A final assumption could be helpful in the end. The protein cycle is said to arise in embryonic development for many muscle and organ groups. Its complexity should be sufficiently small so that coincidences with a low probability do not become a prerequisite. Otherwise the symmetry mechanism would be questionable for statistical reasons. The assumption is that large numbers of suitable sensory nerve fibers with secondary branches to motor neurons on both sides of the spinal cord rise to the brain from the posterior horn. At an early stage of development, the multitude of these nerve fibers could form pairs that cross. It can be assumed that the protein cycle contributes not only to the stimulation of cell division, but also to the gathering of the elements: agonist, antagonist and nociceptive sensor necessary for the construction principle.

Significant leap in evolution

The evolution of living beings has taken the step towards bilateral symmetry with protein-controlled cell division and building on body-side bridging circuits. With this innovation, self-organizing and mutually harmonizing growth on two sides of the body was created. Until the appearance of bilaterally symmetrical forms, nature could only produce primitive life forms and developments.



Depiction: Sketch of a trilobite species from the Cambrian

It is only at the beginning of the Cambrian that many, especially symmetrical, multicellular species can be reliably identified. The so-called Cambrian explosion of biodiversity, in which the first arthropods arose, occurred around 540 million years ago. The Cambrian explosion lasted a short period of only 5 million years. An early, now extinct arthropod class is the trilobite.

A being and an important leap in evolution for whom bilateral symmetry was recognized as an accompanying pattern, but for a long time not as its functional cause.

With discovery and dating in the history of evolution, geneticists were able to show a scientifically founded factor in the development of symmetry around ten years ago. "In a new work, the Cologne geneticist Peter Heger linked the sudden appearance of these animal strains with the creation of the so-called CTCF gene. This is able to influence the effects of the so-called Hox genes, which play an important role in the development of the body plan." Source: „Symmetrie-Gen hatte Anteil an der kambrischen Explosion", 13.10.12, http://derStandard.at.

Development of life forms towards symmetry

The first evolutionary steps in life are marked by the cotyledon development. Central to this is the cell differentiation into two or later three so-called cotyledons. Imagine an egg or a round archetype as a space of origin. Like a membrane, a round cell surface is created within this room, which separates a small part of the room. At the same time, a second cell surface of the same size is created, which rests on the first. This creates the basis for two cotyledons. The first cell areas are called epiblast and hypoblast.

The expansion to three cotyledons is linked to the development of the so-called bilateria, the bilaterally symmetrical tissue animals. Triploblastic tissue animals produce three cotyledons, all of which arise from cells of the epiblast. Endoderm, mesoderm and ectoderm are formed - i.e. the lower, middle and upper cotyledon.

The endoderm produces the digestive tract and all connected units such as liver, thyroid and bladder in all animals. The respiratory tract also emerges later as a protuberance from the front intestine. The endoderm is turned inside during development, the so-called gastrulation. An inner cavity for collecting nutrients is created that is connected to the outside world. The upper cotyledon protects the body from the outside and produces later also the nervous system.

Bones, muscles and connective tissue emerge from the cells of the middle cotyledon, the mesoderm. It is these units that determine the three-dimensional shape of the body. The resulting body cells realize (1) all the physical support functions, in higher development forms this happens with bones and cartilages, (2) all connection functions with muscles and their tendons, which connect them to the bones, and (3) spaces with connective tissue. This lays the foundation for three-dimensional bodies with coordinated pressure and tensile loads.

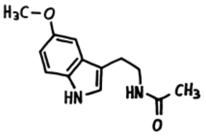
It is interesting that only with the arthropods with about 80 percent of all animals today and the ringworms, did a more developed, orderly nervous system develop. Evolutionarily, all higher nerve systems go back to an original so-called rope conductor nerve system. Like the whole body of the animals themselves, this is bilaterally symmetrical to the longitudinal axis of the body. The third cotyledon and rope ladder nerve system are thus two indications that characterize a narrowly defined course of the evolution in the direction of symmetrical body shapes.

Creation of a separation in right and left

A self-organizing and mutually harmonizing growth on two sides of the body needs a middle or rather a plane of symmetry. How does this middle prevail as such and is there something that stabilizes the separation between right and left? Something that is not symmetrically organized itself could contribute to this. For example, the unpaired arrangement of the pineal gland attracted special attention early on and coined the term third eye. The philosopher Rene Descartes (1596 - 1650) said: "There is a small gland in the brain in which the soul performs its function more specifically than in any other part of the body".

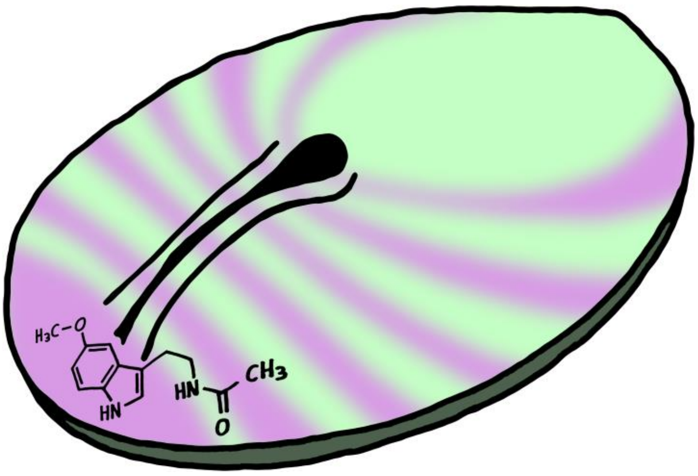
The pineal gland is a small cone-shaped gland on the back of the midbrain. It produces the hormone melatonin, which is released in blood and brain spinal fluid. This also reaches the central channel of the spinal cord and thus the axis of symmetry of the central nervous system. Source: www.wikipedia.de

Melatonin has a chemically simple structure:



We believe that melatonin affects protein and signaling mechanisms in cell division. The interlocking mechanisms in metabolism, cell division and cell differentiation are a broad area of research. Many factors and individual effects are rarely attributable to clear triggers. But it is conceivable that this simple hormone creates a milieu that is avoided by the cells.

If we go back to the beginning of cotyledon development in embryonic development, it is conceivable, but not yet researched, that melatonin could be produced since an early phase. This would fit in. In the early days of cotyledon phase a first sign of the later level of symmetry of the body shows up. The so-called primitive channel forms on the epiblast. New cells migrate along it for heading to migrate through a passage at the end into the space between the cotyledons. The segmented somites that form after this are already in pairs on the right and left of the body's longitudinal axis. The development of the primitive channel or primitive groove begins at a maternal edge of the cotyledon. It is conceivable that the production of melatonin starts at this point.



Depiction: Germinal disc with primitive groove shows alignment of body symmetry for the first time

Logic of science and symmetry

Obviously, the search for scientifically based factors in the development of symmetry is a particularly tough nut. An enormous number of influencing factors complicate an inductive procedure, which would ultimately lead to a generally valid finding. Nevertheless, a purely deductive, mathematical approach would not lead to the goal. The previously known factors and side effects of evolution, genetics and embryonic development were developed with thorough empirical research, without which this article would not have been possible. The key to the proposed logic of the bilaterally symmetrical body shape of higher life forms was the motivation from Emmy Noether's symmetry theorem.

Amalie Emmy Noether was a German mathematician who made fundamental contributions to abstract algebra and theoretical physics. The Noether theorem named after her simply states that there is a conservation factor for every symmetry. Source: www.wikipedia.de. Emmy Noether has thus created a fundamental motivation for mathematics, but also for other sciences, for which she has won great recognition. With Noether's theorem it is sufficient to recognize a symmetry. This already stipulates that there is a conservation factor and that the scientific effort could be worthwhile to research for it. For bilateral-symmetrical life and its evolution, this article suggests a growth mechanism with a protein cycle as corresponding conservation factor.

Bruno Krüger, in May 2020