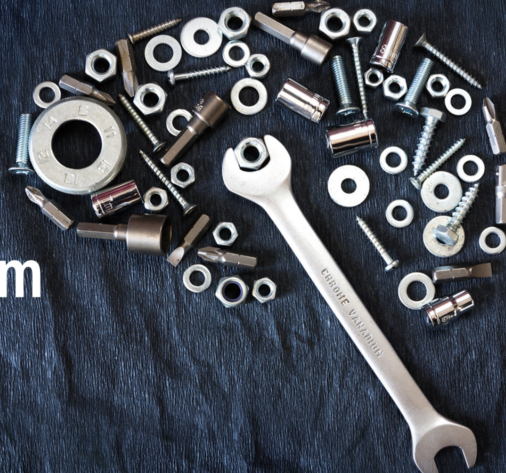
NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

An Anatomic Study of the Automatic Autonomic Nervous System



by
Hollie L. Leavitt
Department of Biology, College of Western Idaho, Nampa, ID

Part I – A Strange Disease

"Hello?"

"Hi mom," said the voice on the other end of the phone. "Armando and I got the results back from our preimplantation genetic testing, and we have four healthy embryos!"

"That's great news! I'm gonna be a grandma!"

Natalia had always dreamed of being a mom and having a little girl. However, after over a year of trying to conceive with her husband Armando, they had been unable to get pregnant. Fearing that something was wrong, Natalia took her concerns to her doctor, and after several months of testing and dead ends with other options, the couple began the process of *in vitro* fertilization, or IVF. After harvesting Natalia's eggs and fertilizing them with Armando's sperm, the couple had decided to have the embryos tested for genetic diseases before determining which to implant.

"I also learned something interesting about our family genetics," Natalia continued. "Apparently, both Armando and I are carriers for a gene that causes a disease called familial dysautonomia, because two of the original six embryos had this genetic condition."

"What's that?" Natalia's mom, Maria asked. "I've never heard of it, and I don't know anyone in our family that has it."

"It's very rare, but I've been researching it a bit," her daughter answered. "It can cause some very strange symptoms: constipation, incontinence, an inability to feel pain, problems with blood pressure becoming too high and at other times too low, an inability to produce tears when crying, difficulty regulating body temperature, even problems with vision when moving from somewhere dark to somewhere light or vice versa. It's really weird!"

Maria continued to talk with her daughter for several minutes. Following their conversation, she immediately went online and looked up familial dysautonomia, or FD, and learned that it is a genetic disease that affects the development and survival of neurons that make up the autonomic nervous system (ANS). Wanting to understand the disease and its strange and diverse symptoms a little better, she began to research the ANS.

Questions

1. What is the ANS and what role does it play in the body?

Credit: Licensed image © Sergiy Gaydaenko | Dreamstime, ID 54076433.

2. Based on your understanding of this system, circle all of the functions below that would be regulated by the ANS:

- Dilation of the pupils
- Turning the pages of a book
- Sneezing
- Lifting weights
- Monitoring light levels in the eye
- Feeling the temperature of water
- Playing volleyball
- Cooking dinner
- Sweating when exercising
- Monitoring changes in blood pressure
- Heart rate
- Monitoring body temperature
- Movement of food through the gut
- Studying
- Tying your shoes
- Driving a car
- Singing
- Breathing rate
- Shopping

3. Explain why someone with familial dysautonomia may have difficulty moving from a dimly lit room into a room that is very bright.

Part II – Divisions of the ANS

As Maria continued her research, she learned that the role of the ANS is to help maintain homeostasis in the body. To do this, it has a sensory component that monitors involuntary body functions (such as heart rate and blood pressure) and a motor component that is able to make changes to the monitored functions to keep them within normal ranges. The motor component of the ANS is subdivided into two divisions: the sympathetic and parasympathetic.

The sympathetic division of the ANS regulates body activities primarily during exercise and under times of stress or emergency. For this reason, it is also sometimes referred to as the body's "fight or flight" system. Under sympathetic activation, the body is prepared to perform optimally at physical tasks such as fighting an enemy or fleeing (hence "fight or flight"). It will activate systems of the body needed for this purpose (e.g., the cardiovascular and respiratory systems) and inhibit systems that are not immediately necessary for the task (e.g., the digestive system). The parasympathetic branch regulates body activities under resting, peaceful conditions. If the body is not facing immediate danger or stress, it will optimize digestion and all activities related to digestion and inhibit other systems. For this reason, the parasympathetic branch is sometimes referred to as the "resting and digesting" system.

Questions

1. Below is a list of involuntarily controlled activities that are regulated by the ANS. Determine whether each reaction in the body would be caused by sympathetic or parasympathetic activation based on what it prepares the body for ("fight or flight" or "resting and digesting").

   - Increased heart rate
   - Increased blood pressure
   - Increased saliva production
   - Dilation of the pupils
   - Increased blood flow to skeletal muscles
   - Increased blood flow to digestive organs
   - Bronchoconstriction
   - Increased peristalsis (movement of food through the digestive system)
   - Increased sweating
   - Decreased heart rate
   - Decreased blood pressure
   - Decreased saliva production
   - Constriction of pupils
   - Decreased blood flow to skeletal muscles
   - Decreased blood flow to digestive organs
   - Bronchodilation
   - Decreased peristalsis
   - Decreased sweating

2. Studies have indicated that some people are more afraid of speaking in public than dying. For people who are uncomfortable with speaking in public, it is quite common to get a dry mouth which then prevents normal movements of the tongue and makes speaking even more difficult. Explain why this would be based on what you have learned so far.

3. A lot of people get nervous when meeting others for the first time in high-stress situations such as job interviews. Explain why your palms may get very sweaty (potentially making that first hand shake embarrassing) in stressful situations.

4. In her conversation with her mother, Natalia listed several signs and symptoms of familial dysautonomia. Predict several additional signs and symptoms that may occur with the disease based on the fact that it interferes with the development and survival of neurons in the ANS.

Part III – Anatomy of the ANS

Use the figure on the following page (Figure 1) to answer the questions below.

Questions

1. Figure 1 represents the nerve pathways and target organs of the sympathetic (left) and parasympathetic (right) divisions of the ANS. Study the diagram to see if you can come up with a reason for why the sympathetic is sometimes also called the "thoracolumbar" division, and why the parasympathetic is often referred to as the "craniosacral" division.

2. Find the lungs near the center of the diagram, then trace the sympathetic motor nerve pathway back from the lungs to the spinal cord. Do the same for the pathway to the lungs from the parasympathetic division. How many consecutive nerves does it appear are in the autonomic pathways (both sympathetic and parasympathetic) that innervate the lungs? Is this consistent for the motor pathways to all of the other target organs represented in the diagram?

3. The neuron that branches directly off the spinal cord in an autonomic motor pathway is known as the preganglionic neuron. This first neuron synapses with the ganglionic (sometimes referred to as "postganglionic") neuron that communicates directly with the target organ. On the sympathetic motor pathway to the lungs, label the "preganglionic neuron" and the "ganglionic neuron." Then do the same on the parasympathetic pathway to the lungs.

4. *Fill-in-the-blanks:* In the sympathetic division, the preganglionic neuron is much ________________ (shorter/longer) than the ganglionic neuron. In the parasympathetic division the opposite is true: the preganglionic neuron is much ________________ (shorter/longer) than the ganglionic neuron.

5. Examine the location of the synapses between preganglionic and ganglionic neurons in the sympathetic branch. They all occur along an area known as the sympathetic trunk and within paravertebral ganglia. Do some research on the sympathetic trunks and then provide a more detailed description of what they are.

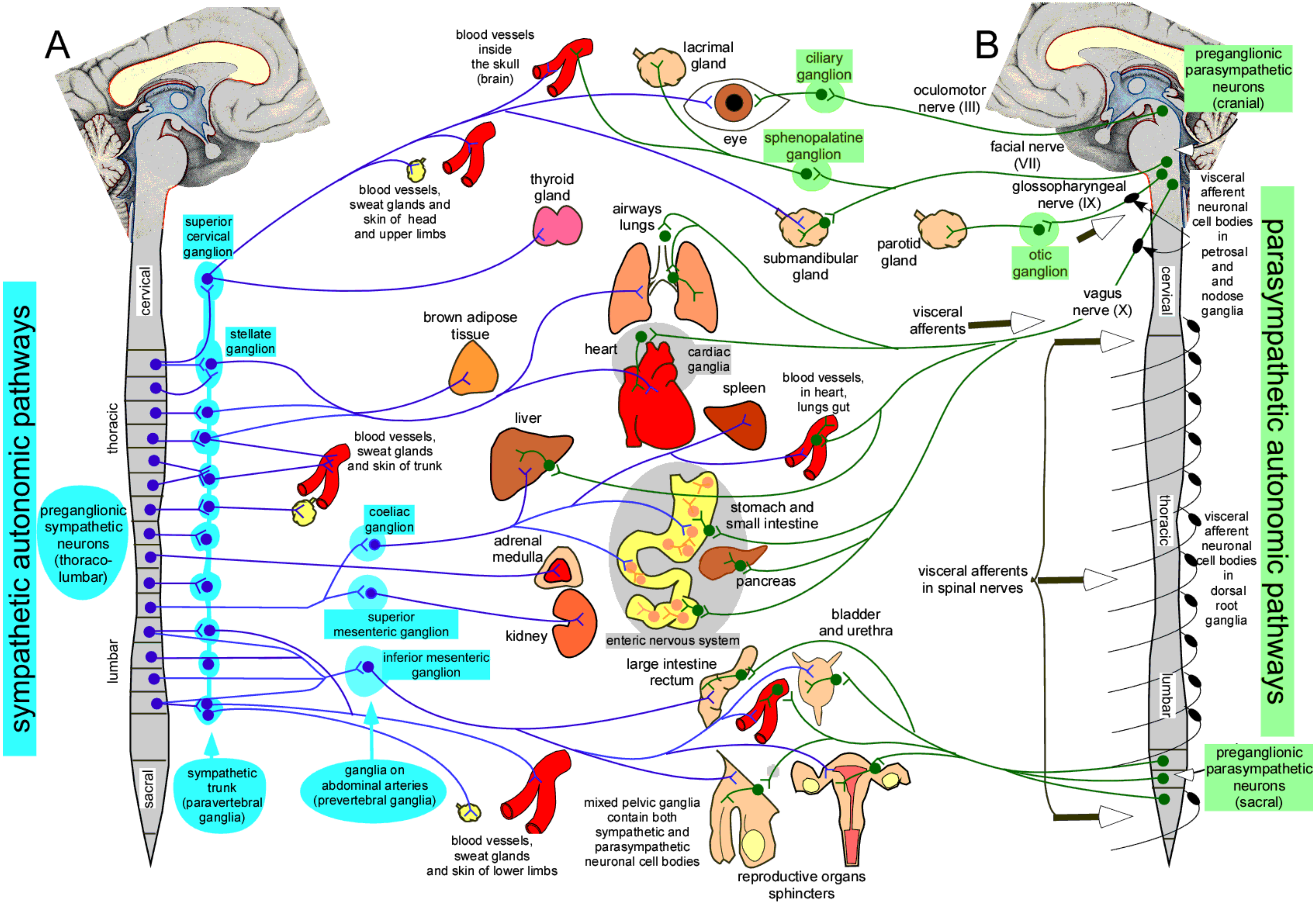


Figure 1. Nerve pathways and target organs of the autonomic nervous system. *Credit:* Blessing, B., and I. Gibbins. (2008). *Scholarpedia* 3(7): 2787. Used in accordance with CC BY-NC-SA 3.0. http://www.scholarpedia.org/article/File:Autonomic_nervous_system_main_figure_Blessing.gif

Part IV – Neurons, Neurotransmitters, and Receptors in the ANS

After learning a little about the general functions and structure of the ANS, Maria continued her research at a local library where she checked out a human anatomy and physiology textbook. From the text she read the following:

> The preganglionic and ganglionic neurons of the ANS can be classified based on which neurotransmitter they release. Neurons that use acetylcholine (ACh) as their neurotransmitter are known as cholinergic neurons and those that use norepinephrine (NE) are adrenergic neurons. All preganglionic neurons in the ANS (both sympathetic and parasympathetic) are cholinergic, as are all parasympathetic ganglionic neurons and the sympathetic ganglionic neurons that innervate sweat glands. Adrenergic neurons include all sympathetic ganglionic neurons except those that innervate the sweat glands.
>
> When a cholinergic neuron releases acetylcholine, the neurotransmitter binds to cholinergic receptors on a ganglionic neuron or on a target organ. There are two subtypes of cholinergic receptors: nicotinic and muscarinic. Nicotinic receptors are found on the dendrites and/or soma of all ganglionic neurons in the sympathetic and parasympathetic branches. They are also found on adrenal medulla cells. Muscarinic receptors are found on all of the target organs of the parasympathetic branch, as well as on sweat glands in the sympathetic branch. When acetylcholine binds to a nicotinic receptor, the effects are always excitatory. When it binds to muscarinic receptors the effect is usually excitatory; however, if the muscarinic receptors are located on the heart, the effect is inhibitory.
>
> Norepinephrine released by adrenergic neurons binds to adrenergic receptors, of which there are two subtypes: alpha (α) receptors and beta (β) receptors. Alpha receptors can further be classified as either α1 or α2, while beta receptors are of three subtypes: β1, β2, and β3. Table 1 below contains more information about alpha and beta receptors including some (but not all) of the areas in the body where they are found and the major effects of norepinephrine binding to these receptor types.

Table 1. Comparison of alpha and beta adrenergic receptors.

	Alpha (α) Receptors		Beta (β) Receptors		
	α1	α2	β1	β2	β3
Location of Receptors/ Effects	All sympathetic target organs except heart and bronchioles. Causes contraction of smooth muscle.	Pancreas (inhibits insulin release) CNS (inhibits sympathetic activity) GI sphincters (causes contraction)	Heart (increases HR and force of contraction) Kidney (stimulates renin release)	Coronary arteries and bronchioles (causes relaxation and dilation)	Adipose (stimulates fat breakdown) Urinary bladder (relaxes bladder wall)
Overall Effect	Excitatory	Excitatory or Inhibitory	Excitatory	Mostly Inhibitory	Excitatory or Inhibitory

Questions

1. Use the information from the "textbook" (paragraphs and table above) to complete the worksheet on cholinergic neurons (see next page, p. 7). Then do the same for adrenergic neurons (p. 8). Once completed, these worksheets will provide you with a nice summary of the neurons, neurotransmitters, and receptor types in the ANS, which can be helpful for studying purposes.

Cholinergic Neurons

Include:

1. ALL preganglionic neurons (sympathetic and parasympathetic)
2. ____
3. ____

Neurotransmitter released:

4. ____

Binds to:

5. ____

6. Nicotinic Receptors

Found on:

- ______________________________
  ____
- ______________________________
  ____

7. Muscarinic Receptors

Found on:

- ______________________________
  ____
- ______________________________
  ____

Effect of ACh binding to nicotinic receptor:

____

____

Effect of ACh binding to muscarinic receptor:

____

____

Adrenergic Neurons

Include:

1. ____

____

Neurotransmitter released:

2. ____

Binds to:

3. ___________________________________

4. Alpha Receptors

Subtypes/Locations:

- ____________________________
- ____________________________

5. Beta Receptors

Subtypes/Locations:

- ____________________________
- ____________________________
- ____________________________

Effect of NE binding to alpha receptors:

α_1:______________________________

α_2:______________________________

Effect of NE binding to beta receptors:

β1:______________________________

β2:______________________________

β3:______________________________

2. Tying it all together! Use the completed worksheets and what you've learned so far to help you fill in the blanks for the sympathetic and parasympathetic motor pathways to the heart:
   a. Sympathetic innervation to the heart exits the spinal cord in the ____________ (thoracic/lumbar) region. Electrical signals first travel down a/an ____________ (cholinergic/adrenergic) preganglionic neuron that synapses with the ganglionic neuron in the sympathetic trunk ganglia. At the synapse ____________ (ACh/NE) is released and binds to ____________ (nicotinic/muscarinic) receptors on the ganglionic neuron. This _____________ (excites/inhibits) the ______________ (cholinergic/adrenergic) ganglionic neuron. At the heart, the ganglionic neuron releases ______________ (ACh/NE), which binds to _______________ (alpha/beta) receptors on the heart, _________________ (stimulating/inhibiting) contraction of the heart.

   b. Parasympathetic innervation to the heart exits the CNS in the ____________ (cranial/sacral) region. Electrical signals first travel down a/an ____________ (cholinergic/adrenergic) preganglionic neuron. At the synapse between the preganglionic and ganglionic neuron ____________ (ACh/NE) is released and binds to ____________ (nicotinic/muscarinic) receptors on the ganglionic neuron. This _____________ (excites/inhibits) the ______________ (cholinergic/adrenergic) ganglionic neuron. At the heart, the ganglionic neuron releases ______________ (ACh/NE), which binds to _______________ (nicotinic/muscarinic) receptors on the heart, _____________ (stimulating/inhibiting) contraction of the heart.

3. Some pharmaceutical drugs act on the alpha or beta receptors that bind to norepinephrine to mimic effects of the autonomic nervous system. Beta blockers are a good example of this. Do some research to learn how a beta blocker works. Then explain how a beta blocker such as metoprolol could be used to treat conditions where heart rate is abnormally high.

4. Beta agonists are pharmaceuticals that can be used to treat diseases like asthma. Do some research on asthma to understand what causes an asthma exacerbation (or attack). Then explain how a beta agonist drug like albuterol reduces symptoms during an asthma attack.

References

Bar-Aluma, B.E. (2003; updated 2021). In: Adam, M.P., H.H. Ardinger, R.A. Pagon, *et al.*, editors. *GeneReviews®* [Internet]. Seattle (WA): University of Washington, Seattle; 1993–2021. <https://www.ncbi.nlm.nih.gov/books/NBK1180/>

Genetic and Rare Diseases Information Center (GARD). (*n.d.*). Familial dysautonomia [webpage]. <https://rarediseases.info.nih.gov/diseases/7581/familial-dysautonomia>

Mendoza-Santiesteban, C.E., J.A. Palma, L. Norcliffe-Kaufmann, and H. Kaufmann. (2017). Familial dysautonomia: a disease with hidden tears. *Journal of Neurology* 264(6): 1290–1. <https://doi.org/10.1007/s00415-017-8486-z>

Norcliffe-Kaufmann, L., and H. Kaufmann. (2012). Familial dysautonomia (Riley-Day syndrome): when baroreceptor feedback fails. *Autonomic Neuroscience* 172(1–2): 26–30. <https://doi.org/10.1016/j.autneu.2012.10.012>