SECTION 3 - THE NERVOUS SYSTEM AND SENSORY PHYSIOLOGY

EXERCISE 3.1   RECORDING THE NERVE ACTION POTENTIAL

Approximate Time for Completion: 1-2 hours

Introduction

This exercise is designed to introduce students to action potentials, to the activity of a living nerve, and to the oscilloscope. Action potentials are often difficult for students to understand, so an explanation prior to the laboratory period is essential. This exercise may be performed as a demonstration and supported by films or CD-ROMs. A description of the procedure, the experiment purpose, the setup, and the operation of the equipment is necessary and will take time. Performing the frog dissection before lab will provide more time for discussion.

Materials

1. Frogs
2. Dissecting equipment and trays, glass probes, thread
3. Oscilloscope, nerve chamber
4. Frog Ringer's solution (see Appendix B for solution recipe, or exercise 5.1)

Textbook Correlations: Chapter 7 – Action Potentials; Conduction of Nerve Impulses

Answers to Questions

1. dendrites and cell body

2. resting membrane potential

3. a.   depolarization

   b.   sodium ions

4. frequency; strength

5. The all-or-none law of nerve physiology states that a neuron either does not "fire" (to any subthreshold stimulus) or it "fires" maximally (to any threshold or suprathreshold stimulus).

6. When both recording electrodes are placed in the extracellular environment, the voltage between them is zero because there is no separation of charges between the two electrodes (no difference in potential). When one recording electrode is placed inside a cell and one is outside, a membrane potential is recorded because the cell membrane maintains a separation of charges, or a potential difference, between the inside and outside of a cell.

7. At rest, the sodium-potassium active transport pump is dominant, pumping sodium ions out and potassium ions into the neuron cell cytoplasm – with ion gates closed. During the production of an action potential, the pumps remain "on" while the sodium channels open first allowing the initial entry of sodium ions into the neuron (depolarization), followed immediately by the potassium channels opening with potassium ions leaving the neuron cytoplasm (repolarization and hyperpolarization). Both ion channels then close allowing the reestablishment of the original resting membrane potential.

8. The strength of a stimulus is coded in a single neuron axon by the frequency of generated action potentials. Stronger stimuli however, will excite a greater number of axons collected within a given nerve to produce a greater response, as demonstrated in lab by the increase in the amplitude of the whole (sciatic) nerve response.

9.   As the strength of the stimulus was increased, more fibers within the nerve were stimulated to produce a greater number of individual neuron all-or-none action potentials, resulting in an overall increase in the amplitude of the recorded sciatic nerve response. The whole nerve "action potential" observed in this exercise was therefore a composite of many individual neuron action potentials firing simultaneously. The whole nerve response, therefore could increase in size when a stronger stimulus was applied since a greater number of neurons responded with simultaneous action potentials.

EXERCISE 3.2   ELECTROENCEPHALOGRAM (EEG)

Approximate Time for Completion: 30 minutes-1 hour

Introduction

This exercise is designed to introduce students to methods for measuring electrical activity in the brain. The recording of "brain waves" is used to measure the neuronal activity of the brain. The electrical activity will be improved in the surface of the skin if first cleansed with an alcohol swab. Since the appearance of the EEG patterns varies from student to student and since only a few students will be able to produce an alpha rhythm, the success of this exercise will be improved if several students are used as subjects.

Materials
  1. Oscilloscope and EEG selector box (Phipps and Bird); or physiograph and high-gain coupler (Narco); or electroencephalograph recorder (Lafayette Instrument Co.)
  2. EEG electrodes and surface electrode
  3. Long ECG elastic band and ECG electrolyte gel
  4. Alternatively, Biopac equipment can be used (Biopac lessons 3 and 4).

Textbook Correlations: Chapter 7 – The Synapse; Acetylcholine as a Neurotransmitter;

Chapter 8 – Cerebral Cortex

Answers to Questions

1.   neurotransmitter

2.   excitatory postsynaptic potential (EPSP)

3.   inhibitory postsynaptic potential (IPSP)

4.   graded

5.   b

6.   a

7.   d

8.   c

9.   An EPSP is produced at a dendrite or cell body of a neuron by the opening of chemically regulated Na^+ and K^+ gates in response to the binding of a neurotransmitter molecule to a membrane receptor protein. EPSPs combine to serve as depolarizing stimuli for the production of action potentials at the axon hillock.

10.   Unlike action potentials, EPSPs are graded, have no threshold, and are capable of summation. Also unlike action potentials, EPSPs decrease in amplitude as they are conducted toward the initial segment (axon hillock).

11. Inhibitory postsynaptic potentials (IPSPs) are produced by inhibitory neurotransmitter molecules. IPSPs result in hyperpolarization of the dendrite or cell body membrane, causing inhibition as the membrane potential is farther removed from the threshold potential.

12. Since alpha rhythms are seen in relaxed subjects with closed eyes and since lowered blood pressure is associated with relaxation one could propose that training subjects to attain alpha rhythms could help enable the subject to lower blood pressure when not being monitored (a form of biofeedback therapy).

13. The EEG recording is compiled from the combined activity of action potentials and synaptic potentials between two electrodes placed on the scalp of a subject. Since the EEG records the potentials difference between the two electrodes, all electrical activity is monitored. Hyperventilation removes carbon dioxide from the body, leading to a rise in pH (respiratory alkalosis). The alkalosis may affect the membrane potential of neurons in the central nervous system and produce alterations in the EEG.

EXERCISE 3.3   REFLEX ARC

Approximate Time for Completion: 30-45 minutes

Introduction

This exercise is designed to introduce students to the simplest reflex arc (stretch reflex) and to the more complex cutaneous reflex (Babinski reflex). Students will perform several reflexes on themselves. Students should be encouraged to work in pairs or small groups. Performing the biceps and triceps jerk tests successfully requires practice and patience, and is most easily accomplished with subjects who are either thin or are well muscled.

Materials
  1. Rubber mallets
  2. Blunt probes
  3. Optional: *Flexicomp* (Intellitool, Inc.) with IBM or Apple computer

Textbook Correlations: Chapter 8 – Spinal Cord Tracts; Cranial and Spinal Nerves

Chapter 12 – Neural Control of Skeletal Muscles

Answers to Questions

1.   sensory; conducting impulses toward the CNS
2.   motor; conducting impulses away from the CNS
3.   muscle stretch
4.   specialized thin muscle fibers (intrafusal fibers) that are innervated by sensory neurons
5.   one
6.   motor (efferent); sensory (afferent)
7.   was a cutaneous reflex: the plantar reflex (Babinski sign)
8.   b
9.   d
10.   a
11.   c
12.   Striking the patellar tendon causes the quadriceps femoris muscles to stretch. When the spindles within these muscles are stretched, action potentials are generated by the sensory neurons within the spindles. These action potentials are conducted by the pseudounipolar sensory neurons into the dorsal gray matter of the spinal cord where the sensory neuron axons synapse with dendrites and cell bodies of the alpha motor neurons. Action potentials produced in the motor neurons are conducted out the ventral root to the stretched muscle, causing the release of ACh and stimulating contraction of the extrafusal fibers in the quadriceps femoris muscle. With the stretch of the muscle over, the muscle spindles cease firing and the reflex is over.
13.   A given stretch reflex involves the synapse between sensory (muscle spindle receptors) and motor neurons at only one level of the spinal cord and the brain is not involved. In the Babinski reflex (a plantar cutaneous reflex), sensory information ascends from the lumbar region of the spinal cord to the sensory cortex of the brain and motor pathways are activated that descend from the motor cortex of the brain to the lumbar region of the spinal cord then out to the muscle.

14.   Damage to the spinal cord at the cervical level can therefore interrupt the normal flow of impulses along the reflex pathway and result in an abnormal (positive Babinski) plantar response. Cervical level damage however, would have no effect on the knee-jerk reflex that requires only that the lower sacral region of the spinal cord be intact. In a reflex, complete pathways to and from the brain are not required.

15.   In the normal condition, descending motor tracts help suppress the spontaneous excitability of neuron in the spinal cord, including those involved in muscle stretch reflexes. Damage to the spinal cord removes this normal suppression resulting in an increase in the excitability of spinal cord neurons including those involved in muscle stretch reflexes, resulting in spontaneous muscle spasms.

EXERCISE 3.4   CUTANEOUS RECEPTORS AND REFERRED PAIN

Approximate Time for Completion: 1 hour

Introduction

This exercise is designed to introduce students to the various types of cutaneous receptors found throughout the body and to the concept of referred pain. By mapping temperature and touch receptors, observing two-point thresholds, and describing sensory adaptation phenomena, students will have a better understanding of how receptors function. The short procedure on referred pain will highlight the importance of the brain in sensory perception. This exercise could be combined with other exercises from unit 3 for an entire laboratory period devoted to the sensory systems of the body. Alternatively, unit 3 can be divided into a first half (exercises 3.1-3.4) and a second half for the special senses (exercises 3.5-3.8). Table 3.1 classification of sensory receptors and figure 3.13 overview of the sensory and motor cortex regions should be discussed with relevance to these exercises.

Materials
1. Thin bristles, cold and warm metal rods; rubber mallets
2. Calipers; cold, warm, and room temperature water baths

Textbook Correlations: Chapter 10 – Cutaneous Sensations

Answers to Questions

1. a
2. c
3. e
4. d
5. b
6. precentral; postcentral
7. Sensory adaptation is the process by which some receptors respond with a burst of activity when a stimulus is first applied, but then quickly decrease their firing rate – adapt to the stimulus – if the stimulus is maintained.
8. Senses of touch and smell adapt quickly; the sense of pain adapts slowly, if at all.
9.   referred
10. phantom limb phenomenon
11. The face, particularly the lips, and fingertips have the highest density of touch receptors. The extensive use of the fingers and lips by infants and by people in general to identify objects, temperatures, textures, and other sensory modalities demonstrates their importance.
12. Cutaneous sensation ultimately projects to the postcentral gyrus of the brain's sensory cortex. The map of this region shows that a larger area of the cortex is devoted to analysis of cutaneous sensations arising from the hands (particularly the fingertips) and the tongue and lips than from most other areas of the body.

13. The hand that was previously in warm water felt colder, while the hand that was previously in cold water felt warmer. This is because the perceived temperature of the lukewarm water is produced by the combined effects of the water temperature on separate receptors for cold and heat. The cold receptors adapted somewhat in the hand that was previously in cold water, so that the perceived temperature was warmer than it would otherwise have been. Similarly, the heat receptors were partially adapted in the hand that was previously in the hot water, so it felt cooler when placed in the lukewarm water.

14. Deep visceral pain is poorly localized, but damage to visceral organs may cause pain in characteristic somatic locations; and by this means, the nature of the damage may be more easily diagnosed. Examples include pain in the left pectoral region, arm and shoulder areas caused by myocardial ischemia and pain referred to the region between the scapulae of the back due to stomach ulcers.

15. The motor cortex is located on the postcentral gyrus. Those areas of the body that have the greatest representation are those that have the greatest number of muscle groups and exhibit the finest muscle activity (such as the face and fingers). Interestingly, those areas of the body that have the largest density of touch receptors also receive the greatest motor innervation and have correspondingly larger representation on both the sensory and motor regions of the cortex, respectively. The motor cortex map reveals that large areas are devoted to the motor activity of the face (particularly the tongue and lips) and hands, whereas relatively small areas are devoted to the trunk, hips, and legs.

16. The sensory receptors transduce different forms of energy into nerve impulses that are transmitted to our brains for interpretation. The brain interprets impulses arriving along different neural pathways as a compilation of unique sensations from particular receptors or regions in the body. Our perceptions, therefore, are the result of this blend of sensory input applied to a background of continuous and dynamic conscious nerve activity. The role of the brain in sensory perception is shown by the phantom limb phenomenon, in which the brain is "tricked" by the arrival of impulses along nerves that had originally served the missing limb and, and as a result of the amputation, the brain mistakenly refers the pain to the missing limb.

EXERCISE 3.5   EYES AND VISION

Approximate Time for Completion: 1 hour

Introduction

This exercise is designed to introduce students to the structure and function of the eye. Remind students to be careful with the all instruments such as the ophthalmoscopes, so that damage to the eye or internal structures does not occur. This exercise could be combined with other exercises from unit 3 (especially 3.6-3.8) for an entire sensory system laboratory period.

Materials
1. Snellen eye chart and astigmatism chart
2. Wire screen and meter stick
3. Ophthalmoscope
4. Lamp
5. Red, blue, and yellow squares on larger sheets of black paper or cardboard
6. Ishihara color blindness cards

Textbook Correlations: Chapter 10 – The Eyes and Vision; Retina

Answers to Questions

1.   cones; three

2.   blind spot; optic disc

3.   vitamin A

4.   ganglion; bipolar

5. ganglion

6. a. *Visual acuity* is the ability of the eye to resolve points in a figure, which is related to the clarity of vision.

    b. *Accommodation* is the ability of the eye to focus the image of an object on the retina when the object is located at different distances from the eye.

7. b

8. d

9. e

10. a

11. c

12. The iris controls the aperture of the pupil. The circularly arranged muscles in the iris cause constriction of the pupil following parasympathetic stimulation, whereas the radial muscles cause dilation of the pupil following sympathetic stimulation. In bright light, parasympathetic stimulation of the circular muscles causes constriction of the pupil, while in dim light sympathetic stimulation of the radial muscles causes the pupil to dilate and let more light in.

13. Changes in the curvature of the lens are brought about by changes in the tension applied by the attached ciliary muscles and suspensory ligaments. When the object is 20 feet or more from the eyes the ciliary muscle is relaxed and the lens is in its flattest, least convex shape. As the object is brought closer to the eyes the ciliary muscle contracts, putting slack into the suspensory ligament. This allows the lens to become thicker, increasing its refractive power so that the image remains focused on the retina.

14. Persons with myopia are nearsighted, unable to see distant objects clearly. Myopia is characterized by an elongated eyeball that causes the focal point to land in front of the retina, resulting in blurred vision. Glasses with concave lenses will spread the incoming light rays, thereby moving the focal point back onto the retina and reestablishing clear vision.

15. Carotene in yellow-orange plants (such as carrots) is a precursor to vitamin A. Vitamin A is a precursor of retinene, the pigment part of rhodopsin. Since rhodopsin is needed for the photochemical reaction responsible for excitation of the rods and good vision under low illumination, eating carrots can improve night vision if the person is deficient in vitamin A from either animal food sources or from plant food sources (carotene). Eating carrots, however, has no effect on the shape of the eyeball and will not help improve blurred vision from myopia or hyperopia.

16. We see a great variety of colors, but according to the Young-Helmholtz theory, we have only three types of cones producing color vision. The color variations are produced by the integration of these three types of inputs to the brain. Since there are no photoreceptors in the optic disc (blind spot) of the retina, there is no neural representation of this area of the retina in the brain. Nevertheless, we do not see a hole in the visual field because the brain "fills in" or "creates" the image that we ultimately see.

EXERCISE 3.6   EARS: COCHLEA AND HEARING

Approximate Time for Completion: 30 minutes

Introduction

This exercise is designed to introduce students to the anatomy of the ear and processes involved in hearing. Procedures include the conduction of sound waves through bone applying both the Rinne and Weber's tests for conduction deafness. Students also will be introduced to the binaural localization of sound. This exercise could be combined with other exercises from unit 3 for an entire laboratory period devoted to the sensory systems of the body.

Materials

1. Tuning forks
2. Rubber mallets

Textbook Correlations: Chapter 10 – The Ears and Hearing

Answers to Questions

1. malleus, incus, stapes

2. tympanic membrane

3. cochlear duct

4. basilar membrane

5. oval window

6. spiral organ of Corti

7. Sound waves in air cause vibrations of the tympanic membrane, generating movements of the middle ear ossicles. As the stapes pushes against the oval window compression waves of endolymph are set up that cause vibrations of first the vestibular, then the basilar membranes. As the projections from the moving hair cells are contacted by the overhanging tectorial membrane, the hair cells are stimulated to produce nerve impulses that travel out the cochlear nerve. The cochlear nerve joins the vestibular nerve forming the vestibulocochlear nerve, cranial nerve VIII.

8. The pitch of a sound determines the pattern of vibration of the basilar membrane. Low pitches cause the basilar membrane to vibrate maximally closer to the apex, whereas higher pitches cause maximum vibration of the basilar membrane closer to its base. Hair cells in different regions of the basilar membrane are thus maximally excited in accordance with the pitch of the sound. The loudness of a sound is related to the amplitude with which the basilar membrane is displaced and thus is related to the extent of activation of the hair cells in a given region of the membrane. Nerve impulses will thus be produced with greater frequency in the nerve fibers serving the more loudly stimulated sensory cells. The brain receives this information at the temporal lobe with high notes interpreted at higher regions and low notes interpreted at lower regions.

9. If a person with otosclerosis performed the Rinne test, he or she would hear the sound when the tuning fork was placed against the mastoid process of the temporal bone but not when the tuning fork was placed outside the ear. This is because sound waves can stimulate the inner ear by conduction through bone (bypassing the middle ear) but cannot be transmitted by the middle ear ossicles. In Weber's test the sound will appear louder in the ear with otosclerosis, just as it does in a person with normal hearing who plugs one ear. This is because the brain can pay more attention to sounds coming to the ear by bone conduction when distracting noises from the room are eliminated.

10. Bending of the hair cell stereocilia causes ion channels in the membrane to open, which in turn depolarizes the hair cells. Each depolarized hair cell then releases a transmitter chemical, believed to be glutamate that stimulates an associated sensory neuron. In the animal kingdom the stereocilia sensitivity to very slight mechanical movement would prove useful wherever small displacements are required for sensation of movement.

EXERCISE 3.7 EARS: VESTIBULAR APPARATUS - BALANCE AND EQUILIBRIUM

Approximate Time for Completion: 5-10 minutes

Introduction

This exercise introduces students to the vestibular apparatus of the inner ear. It demonstrates the development of vestibular nystagmus, and offers the opportunity to discuss the physiology of equilibrium and balance. Care should be taken so that students do not become motion sick or injured from a fall as a result of the vertigo created by excessive turning in the swivel chair.

Materials

1. Swivel chair

Textbook Correlations: Chapter 10 – Vestibular Apparatus and Equilibrium

Answers to Questions

1. vestibular apparatus
2. semicircular canals
3. saccule; utricle; vestibular
4. endolymph
5. eighth (VIII); vestibulocochlear
6. vertigo
7. Inertia can be described as the tendency of matter such as the endolymph fluid in the vestibular apparatus to remain at rest if at rest, or, if moving, to keep moving in the same direction. When a person begins to spin, the inertia of the endolymph causes the cupula to bend in the opposite direction. As the spin continues, however, the inertia of the endolymph is overcome and the cupula straightens. At this time, the endolymph and cupula are moving in the same direction and at the same speed. If the movement is suddenly stopped (deceleration or negative acceleration), the greater inertia of the endolymph causes it to continue moving in the original direction of spin and to bend the cupula in that direction – causing stimulation of the underlying hair cells.
8. Rotation along one of the planes of the semicircular canals causes movement of endolymph. The inertia of the endolymph results in the bending of the cupula, which protrudes into the ampulla region of the semicircular canals. Bending the cupula, in turn, bends the embedded hair cell processes leading to the generation of action potentials. The frequency of action potentials along the sensory nerve fiber that serves the hair cell changes, either decreasing or increasing depending on the direction in which these processes are bent. The change in action potential frequency from each vestibular apparatus is transmitted along the vestibulocochlear nerve ultimately to the brain, which interprets these changes as body movement and direction. When the chair is suddenly stopped, the endolymph follows the inertia forward and the hair cells respond as described.
9. The spinning or rotational movement of a somersault would activate the semicircular canals, mainly the anterior. A cartwheel performed with the head bent to the shoulder would mainly activate the posterior semicircular canals. The fast acceleration of a car would be horizontal, activating mainly the utricle.
10. No. This is because the inertia has been overcome and all components within the semicircular canals are moving with the same velocity. Under these conditions, as well as at rest, the hair cells are no longer bent.
11. Vertigo, or the lack of ability to maintain equilibrium accompanied by an illusion of movement, or spinning, may occur as a result of a rapid acceleration or deceleration which activates the semicircular canals or otolith organs of the utricle and saccule. When this occurs the orienting reflexes are unable to adjust fast enough to accommodate the change in velocity. This may be accompanied by feelings of nausea, which are generated in the medulla oblongata. Activation of the autonomic nervous system as a result of sensory input from the inner ear may result in nausea and vomiting.

EXERCISE 3.8   TASTE PERCEPTION

Approximate Time for Completion: 15 minutes

Introduction

This exercise is designed to introduce students to the structure of the tongue, tongue papillae, and how taste buds participate in the four taste modalities. The two cranial nerve pathways involved in taste perception are also presented. This exercise could be combined with other exercises from unit 3 for an entire laboratory period devoted to the sensory systems of the body.

Materials

  1. Cotton-tipped applicator sticks
  2. Solutions of 5% sucrose, 1% acetic acid, 5% sodium chloride, and 0.5% quinine sulfate
  3. Fruit (apples, grapes, or others)

Textbook Correlations: Chapter 10 – Taste and Smell

Answers to Questions

1. hydrogen ion

2. sodium ions – modified by the anion

3. Taste receptors are not thought to be distributed by type in different regions of the tongue, according to the consensus of researchers in this field. However, students can determine for themselves if this is true by performing this laboratory exercise.

4. The sweet and bitter tastes are produced by interaction of taste molecules with specific membrane proteins. Most organic molecules taste sweet to varying degrees. Bitter taste is evoked by quinine and other unrelated molecules. Both sweet and bitter sensations are mediated by receptors that are coupled to a type of G-protein known as gustducin. Dissociation of the gustducin G-protein subunit activates second-messenger systems, leading to depolarization of the corresponding receptor cell. The second-messenger system for sweet (sugars) is cAMP whereas that for sweet (aspartame) is inositol triphosphate (IP_3) to diacylglycerol (DAG).

5. Chemical senses are those that require molecules to be dissolved in fluid with detection done by chemoreceptors. Furthermore, since olfaction and gustation respond to chemical changes in the external environment, they are also considered to be exteroceptors. In both senses, chemicals must first be dissolved in food or drink (gustation) or airborne odorant molecules dissolved in mucosal fluid (olfaction) before the receptors can be stimulated. The sense of olfaction strongly influences the sense of taste, as can be verified by eating an onion with the nostrils pinched together.

6. (The students must evaluate their own data to see if their data support the traditional mapping of taste distribution or the more current concepts of taste bud function.)

7. No, although a thousand different genes code for a thousand different olfactory receptor proteins the fact that we can detect ten times this many different odors probably means that the brain integrates signals from several sensory neurons and then interprets the varying patterns as characteristic for a particular odor.