AP® BIOLOGY
2007 SCORING GUIDELINES

Question 2

Cephalization and the development of a brain were important steps in animal evolution.

(a) **Discuss** the evolutionary origin and adaptive significance of cephalization in animal phyla. **(3 points)**

- **Cephalization (1 point)**
  Defined: The concentration of the nervous system toward the anterior end of the organism
  OR
  Association: Cephalization tied to bilateral symmetry development

- **Origin (1 point)**
  Origin identification: (Platyhelminthes/flatworms)
  OR
  Evolutionary progression of development

- **Adaptive Significance/Advantage (1 point)**
  Efficient response to a stimulus (e.g., protection, predation, avoidance, movement toward or away)
  During movement sensory organs encounter the environment first

(b) **Describe** the development of the nervous system in the vertebrate embryo. **(4 points maximum)**

- **Tissue** of origin **(1 point)**
  - Ectoderm gives rise to the nervous system.
- **Processes** of development **(2 points)**
  - Neurulation described (neural tube formation) Note: The notochord does not become the nerve cord.
  - Other nerve development processes
    - Neural crest cells migrate to form the peripheral nervous system
    - Anterior portion of the neural tube/cord bulges to become the brain or brain regions
- **Endpoints** with structures described at the end of a process step of development **(1 point)**
  - The ectoderm folds into the neural crest/tube or dorsal nerve/spinal cord
  - Neural tube expands or develops into developmental brain region (e.g., fore-mid-hind brain, prosen-mesen-rhombencephalon)
  - Spinal column/vertebrae/cranium that protects the CNS
- **Signaling (1 point)**
  - Notochord (mesodermal in origin) signals or directs development of neural tube (ectodermal in origin)
  - *Hox* genes, morphogens (diffusible developmental signal)

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Question 2 (continued)

(c) At the sound of shattering glass, people quickly turn their heads. **Discuss** how the human nervous system functions to produce this tynme of response to an external stimulus. **(5 points)**

- **Stimulus/Intermediating Structure of Receptor Action (1 point)**
  Stimulus (sound waves, pressure, heat, etc.) producing an appropriate receptor action (eardrum vibrating, cochlear hairs vibrating or bending, pressure receptors firing, heat receptors firing, etc.)
- **Input/Sensory/Afferent (1 point)**
  Signal direction toward the central nervous system
- **Integration (1 point)**
  Processing/Interpretation by CNS
  Interneurons/Association/Communicating/Internuncial
- **Output/Motor/Efferent Response (1 point)**
  Signal direction toward effectors (peripheral NS) **or** description of the response or autonomic nervous response (e.g., increase in blood pressure or heart rate, muscle contraction **but not just** turning of head)
- **Possible Elaboration (1 point)**
  Neural electrophysiology (e.g., action potential, neurotransmitters, synapse)
  Neuron structure and impulse pathway
  Sensory physiology

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2A1

a. Early cephalization evolved at around the time of bilateral symmetry— flatworms show primative cephalization, with a more condensed nerve bundle at the anterior end. Earthworms & other annelids have the same or similar first example of 'true brains', & the ventral nerve cord that generally follows. From these examples it can be concluded that brains developed from dorsal nerve cord regions at the anterior end of the organism. Cephalization in itself is adaptive because it allows for greater coordination of the body's impulses & movement. Cnidarians & other early animals that only possessed a nerve net could only respond locally to stimuli with cnidocytes, etc., but a more advanced response is possible in cephalized phyla. Cephalization also allows for more concentrated interneurons, & therefore deeper processing of sensory information as opposed to simple reflex arcs. This allows for a better adaptive response toward predators, environmental changes, & other events.

b. As the three germ layers form in the early embryo, the nervous tissue develops from the ectoderm. Following gastrulation, neurulation occurs— the folding in of the ectoderm to create a nerve cord on what will become the dorsal side. Once the nerve cord is in place, nerve cells proliferate. Segmentation also occurs, and this is when the segmented vertebrate spinal cord develops; at this time, nerve cells also begin to migrate out of the nerve cord and throughout the rest of the embryo, forming a complex nerve network. Within the brain, the hindbrain develops first; it includes the medulla, brain stem & other primitive parts of the brain that affect physiological function. Depending on how advanced the vertebrate is, the mesencephalon & telencephalon later develop, giving rise to the limbic system & cerebrum, respectively & cerebellum

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C. The head-turning response is a reflex arc — a split-second response involving minimal sensory processing. The signal originates, in this case, in the hair cells in the inner ear. The mechanical deformation of the hair cell triggers the depolarization of adjacent sensory nerve cells by opening transmembrane Na^+ ion channels. This depolarization generates an action potential which travels through the sensory nerves between the ear + the brain. Since this is a reflexive movement, the signal does not travel through many interneurons once it reaches the brain, but instead travels through motor neurons, where it continues until it reaches neuromuscular junctions in the neck. As in the rest of the nervous system when the signal reaches the postsynaptic cell it triggers the release of neurotransmitters that act to depolarize the postsynaptic cell. In the case of a muscle cell, acetylcholine is the neurotransmitter used. When the muscle cell membrane is depolarized, Ca^{2+} ions are released from the sarcoplasmic reticulum, triggering the contraction of all the nearby muscle cells in the area. This whole exchange takes a few milliseconds, with each action potential generated in microseconds.

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2B1

The cephalization of animals increases as evolution progresses. Early animals lacked cephalization or had simple structures such as nerve nets found in radial symmetry species. Cephalization is a characteristic of bilateral animals and is very high in the Chordates. It accounts for the higher thinking accomplished by these animals.

The development of a vertebrate embryo gives rise to three germ layers; the endoderm, mesoderm, and ectoderm. The ectoderm is the outer layer that gives rise to the skin and nervous system of the organism. All chordates have a dorsal nerve chord and a notochord which later gives rise to a vertebral column.

The nervous system is responsible for the entire process of sensing, interpretting, and responding to stimulus. At the sound of glass shattering, sensory receptors in the ear pick up on the sound and send a nerve impulse to the brain where interneurons connect the impulse to various parts of the central

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2B2

nervous system and then to motor neurons which carry the impulse to ~~form~~ an effector (a muscle) which responds by turning the head. This entire process is contributed to the workings of the nervous system.

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2C1

a) Cephalization was one of the most important terrestrial adaptations in animal evolution. the ability to sense food was important to predators, while prey was able to escape thanks to abilities such as sight, hearing, and touch. Cephalization originated as species evolved to bilateral symmetry where a frontal region with sensory adaptations was clearly defined from a back or dorsal region.

b) The vetebrate embryo has a few similarities among all its species, two of which being a notochord and hollow nerve chord. Both of these structures develops early in an embryo. The notochord is like a cluster of nerve cells which can be likened to an early brain. Similarly, the hollow nerve cord contains nerve cells which run along the body of a vertebrate and can be likened to a spinal chord.

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2C2

C) When a glass shatters, the inner ear picks up the vibrations and sensory cells in the ear respond to those vibrations. Once a nerve cell is triggered, the electrical impulse travels down an axon, passing the impulse on until a synapsis is reached. Neurotransmitters cross those gaps and pass the impulse on to the next nerve cell. This message is quickly received by the brain which then sends the same quick impulse in much the same manner from the movement control center in the cerebellum, to muscles in the body which then turn the human head. All of this happens in another instant because axons quickly send the message.

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Question 2

Overview

This question was designed to measure students' ability to integrate evolution, development, and processes of the nervous system. Part (a) concerned cephalization as it relates to animal diversity, followed in part (b) by embryonic development of the nervous system in vertebrates, and ending in part (c) with a discussion of how the human nervous system responds to a stimulus.

Sample: 2A
Score: 10

In part (a) the student received 1 point for defining cephalization. Evolutionary progression is also described in the comparison of the nerve net of the cnidarians to the phyla that have cephalization. This progression garnered 1 point. The significance point was earned by stating that cephalization "allows for a better adaptive response toward predators, environmental changes . . . "

In part (b) the correct identification of the ectoderm accounted for 1 point. The process of neurulation is explained by the folding of the ectoderm to create a dorsal nerve cord. This explanation earned 1 point for process and 1 point for the endpoint of the process.

In part (c) the student correctly identifies the deformation of the hair cells as a result of the mechanical stimulus and was awarded 1 point. The sensory neurons to the brain earned the input point. The correct use of interneurons in context received 1 point. The motor neurons were explained as causing the contraction of the muscle, thereby earning the output point. The explanation of the neurophysiology from the neurons to the muscle cell membrane would have earned 1 point for elaboration, but the student had already earned 10 points.

Sample: 2B
Score: 7

In part (a) the origin point was earned by associating cephalization with bilateral symmetry. Evolutionary progression is then explained, from animals that had no cephalization (only a nerve net) to animals with bilateral symmetry and ending with chordates. This description was awarded 1 point.

For part (b) the student properly identifies the ectoderm as the origin of the nervous system and received 1 point. The endpoint of the vertebral column merited 1 point because the student properly designates the vertebral column as coming from the notochord and associates it with the dorsal nerve cord as a collective structure.

In part (c) the description of the sensory receptors in the ear picking up the sound did not earn a point for stimulus, because no specific action by the stimulus on some intermediary structure (eardrum vibrating or deformation of hair cells in the cochlea) is mentioned. The input of the message to the brain earned 1 point. The student goes on to discuss interneurons connecting the impulse to parts of the central nervous system and received 1 point for integration. The output from the brain to the motor neurons was also awarded 1 point (alternatively, this point could have been earned for the impulse going to the effector).

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Question 2 (continued)

Sample: 2C
Score: 4

In part (a) the student provides an appropriate terrestrial adaptation of cephalization for sensing food in predation and earned 1 point. The origin of cephalization in relation to bilateral symmetry was granted 1 point.

No points were awarded in part (b).

In part (c) the student did not receive credit for mentioning sensory cells in the inner ear because no action of an intermediary or a specific sensory receptor is attributed to the vibrations. The student earned 1 point for input to the brain and 1 point for the output from the brain to the muscles. No point was awarded for integration because there is no mention of processing in the cerebellum.