As educators, we are continually designing new methods and procedures to enhance learning. During this process, good ideas are frequently generated and tested, but the extent of such activities may not be adequate for a full manuscript. Nonetheless, the ideas may be quite beneficial in improving the teaching and learning of physiology. *Illuminations* is a column designed to facilitate the sharing of these ideas (illuminations). The format of submissions is quite simple: a succinct description of about one or two double-spaced pages (less title and authorship) of something you have used for the classroom, teaching, lab, conference room, etc. You may include one or two simple figures or references. Submit ideas for inclusion in *Illuminations* directly to the Associate Editor in charge, Stephen DiCarlo (sdicarlo@med.wayne.edu).

**POSTSYNAPTIC POTENTIAL SUMMATION AND ACTION POTENTIAL INITIATION: FUNCTION FOLLOWING FORM**

The mechanisms and physiological significance of postsynaptic potential summation and action potential initiation are among the most difficult concepts for students to grasp. To help students understand these concepts, we emphasize that neurons have three distinct functional zones: 1) the “input,” 2) the “integrative,” and 3) the “conductive” zones (Fig. 1). The input zone, which consists of the dendritic and somatic domains, contains ligand-gated ion channels that are activated by neurotransmitters (ligands) secreted by presynaptic terminals. Activation of the input zone creates a postsynaptic potential. The integrative zone, which consists of the axon hillock domain, summates the postsynaptic potentials and initiates an action potential. Importantly, action potentials depend on the activation of voltage-gated ion channels. The conductive zone, which consists of the axon domain, propagates the action potential. Thus postsynaptic potentials require activation of ligand-gated ion channels located on the postsynaptic membrane, whereas action potentials require activation of voltage-gated ion channels located at very high concentrations along the axon hillock and at lower concentrations along the remainder of the axon. It is important to note that the input zone, dendrites, lack voltage-gated ion channels, whereas the soma contains low concentrations of voltage-gated ion channels. The different location and concentration of ligand-gated vs. voltage-gated ion channels provide the basis for understanding the differences between postsynaptic potentials and action potentials (Table 1).

The uneven concentration of voltage-gated ion channels differentiates the integrative from the conductive zones. Specifically, the integrative zone, which contains the axon hillock, is the trigger zone, or decision-making point. That is, because this area has the highest concentration of voltage-gated ion channels, it has the lowest threshold for initiating an action potential. In contrast, the remainder of the axon, with a lower concentration of voltage-gated ion channels, lacks the necessary threshold to initiate an action potential.

*Fig. 1. Features of a motor neuron: ion channel distribution, domains, functional zones, and input and output signals.*
channels, is adapted for action potential propagation (Fig. 1).

We also emphasize that a motor neuron receives over 1,000 presynaptic terminals (1), and each postsynaptic potential is below threshold (Table 2). Thus postsynaptic potentials must summate to reach the depolarization threshold. Summation of postsynaptic potentials occurs when a presynaptic neuron fires repeatedly at a high rate (“temporal summation”) or when several presynaptic terminals fire at the same time (“spatial summation”) or from a combination of temporal and spatial summation. When the threshold for voltage-gated sodium channels activation is reached (at the hillock) an action potential occurs. This is an all-or-none process, like flushing a toilet: it either occurs or it does not. Finally, we compare a neuron with a circuit of the nervous system. In this analogy, dendrites and the soma are the afferent limb, and the axon is the efferent limb. The axon hillock is the integrative center, gathering information received by the dendrites and soma and deciding to fire an action potential or not. This approach to understanding postsynaptic potential summation and action potential initiation is an excellent example of function following form that students appreciate.

### Table 2. Features of postsynaptic potentials and action potentials

<table>
<thead>
<tr>
<th>Feature</th>
<th>Postsynaptic Potential</th>
<th>Action Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>Small (100 μV to 10 mV)</td>
<td>Large (70–110 mV)</td>
</tr>
<tr>
<td>Duration</td>
<td>Brief to long (5 ms to 30 min)</td>
<td>Brief (1–10 ms)</td>
</tr>
<tr>
<td>Summation</td>
<td>Graded</td>
<td>All or none</td>
</tr>
<tr>
<td>Signal</td>
<td>Hyperpolarizing or depolarizing</td>
<td>Depolarizing</td>
</tr>
<tr>
<td>Propagation</td>
<td>Passive</td>
<td>Active</td>
</tr>
</tbody>
</table>

**REFERENCES**


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**MYELINATED VS. UNMYELINATED NERVE CONDUCTION: A NOVEL WAY OF UNDERSTANDING THE MECHANISMS**

The concepts and physiological significance of saltatory nerve conduction are often difficult for students to grasp. Most physiology textbooks contain a variation of: “... the action potential leaps from node to node along the axon ...”. A clever analogy of these events has recently been published (1); however, the mechanism mediating saltatory nerve conduction was not included. To help students understand the mechanism mediating saltatory nerve conduction, we emphasize that action potential propagation depends on the activation of voltage-gated sodium channels. We point out that unmyelinated axons have voltage-gated sodium channels along the entire length of the membrane. In contrast, myelinated axons have voltage-gated sodium channels only in the nodal spaces. Nodal spaces (nodes of Ranvier) are unmyelinated spaces ~2 μm long. The unmyelinated spaces are located at ~1-mm intervals along the axonal surface (internodal spaces: myelinated wraps) (2). Action potential propagation along unmyelinated axons requires activation of voltage-gated sodium channels along the entire length of the axon. In sharp contrast, action potential propagation along myelinated axons requires activation of voltage-gated sodium channels only in the nodal spaces. With this understanding, the students realize that action potential propagation is much faster along myelinated axons. To further emphasize this point, we provide the following example. Consider a myelinated axon 1,500,000 μm long. Only 0.2% of the myelinated axon (2,994 μm) contains nodes of Ranvier where depolarization occurs. Similarly, a myelinated axon with a total surface area of 1,178,100 μm² has only 2,352 μm² of membrane (0.2%) where depolarization occurs (Table 1). Assuming equal time constants for activation of voltage-gated sodium channels along myelinated and unmyelinated axons, the myelin sheath reduces the length and surface area where depolarization occurs and increases action potential propagation velocity. This concept is illustrated in Fig. 1.

### Table 1. Axon length and surface area divided into internodal and nodal spaces

<table>
<thead>
<tr>
<th>Feature</th>
<th>Length, μm²</th>
<th>Length, %</th>
<th>Surface Area μm²</th>
<th>Surface %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axon</td>
<td>1,500,000</td>
<td>100</td>
<td>1,178,100</td>
<td>100</td>
</tr>
<tr>
<td>Internodal space</td>
<td>1,497,006</td>
<td>99.8</td>
<td>1,175,748.5</td>
<td>99.8</td>
</tr>
<tr>
<td>Nodal space</td>
<td>2,994</td>
<td>0.2</td>
<td>2,352.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>

*Axon length, 1,500,000 μm; "internodal space (myelinated wraps of Schwann cells), set at 1,000 μm; "nodal space (unmyelinated nodes of Ranvier), set at 2 μm; "estimated as follows: = length × number. Number = [axon length/internodal space length + nodal space length] = [1,500,000/(1,000 + 2)] = 1,497; e.g., internodal length = 1,000 × 1,497 and nodal length = 2 × 1,497; "estimated as follows: = [(μm²)]. Axon diameter, 1 μm."
REFERENCES


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Fig. 1. Length of axon where polarization occurs in unmyelinated and myelinated axons.