ILLUSTRATIONS

Don’t slap me hard!: human emulator of axon

Aki Konomi and Katsuhiko Yokoi
Department of Human Nutrition, Seitoku University Graduate School, Chiba, Japan

Submitted 4 January 2018; accepted in final form 3 June 2019

INTRODUCTION

In learning the physiology of nerves, students often have difficulty understanding the basic concepts of nerve conduction. Many students often equate learning with memorizing knowledge (2). To address this problem, Giuliodori and DiCarlo (4) devised a numerical illustration to deepen the understanding of saltatory conduction. An active learning method was developed by Gathers (3) to teach students who had difficulty in understanding saltatory conduction per se. Luchi et al. (7) developed an educational game to help students understand the molecular mechanisms of the action potential. Machado and Mello-Carpes (8) tested an open-ended, student-led activity to aid in learning action potential and found this activity to be favorably accepted by the students.

We developed a teaching method especially for students in the allied health sciences, who have difficulty in mechanistically connecting the most fundamental concept of nerves, i.e., action potential and refractory period to propagation of excitation of nerves. Our nutrition students remembered such technical terms, but they could not correctly combine these terms to build a correct statement explaining the propagation of action potentials along nerves. All of our knowledge begins with experience, according to Kant (5). The students required additional experiences before they would make correct inferences. Therefore, we created a game for students to actively learn nerve conduction by imitating action potential in the axonal membrane. In this game, each student plays a role representing part of the axonal membrane. We planned to test the learning efficacy of the developed game by comparing the proportion of nutrition students who correctly answered the question about nerve conduction before and after playing the game.

METHODS

Participants

In an advanced nutrition course, which is for female students holding a diet technician license in Japan, all 11 students were first given a didactic classroom introduction to action potentials, and then they played the game. Students were asked to explain after the didactic session, “Why do impulses pass in one direction in the natural situation, although an axon can conduct in either direction?” Students were required to provide a mechanistic explanation of this phenomenon that suggests the generation of action potential in the initial segment of the axon (i.e., the proximal end) under natural conditions, as is typical in motoneurons, bidirectional electric current evoked by an action potential, the prevention of backward propagation of impulses opposite to the advancing direction because of the refractory period, and the unsymmetrical constitution of synapses that finally prevents reverse transmission of neuronal signals. This question was asked again after students played the “Slappy Game.” After the first-time question in the didactic session, some students spontaneously had a discussion about this issue without the presence of the tutor. One student hit upon an idea that a game imitating the nerve conduction may help teach this issue and consulted with the tutor to establish rules for a learning game. The tutor gathered the students and debriefed this activity for ~15 min. The activity took ~15 min. The posttest question was given 1 wk later.

The rules of the Slappy Game (shown below) were presented to the students before playing the game.

Rules of the Slappy Game

The learning activities described here can be used in coordination with Ganong’s textbook chapter “Excitable tissue: nerve” (1) or a corresponding chapter in an alternative textbook. (We used the Japanese alternative for allied health students corresponding to the 19th edition of Ganong’s textbook in this study.) Students stand in lines and emulate the action potential conduction by slapping their neighbors. The objective of Slappy Game is to understand the “all-or-none law,” “propagation of excitation in nerves,” “refractory periods,” “orthodromic and antidromic conduction,” and “saltatory conduction.” Students who participate in this game can learn about these principles of neurophysiology by acting out roles as axonal signaling components. The kinds of characters used in the game are shown in Fig. 1. Required materials are only the students as players, a tutor, chairs, and straight rulers. Students playing the game will slap their immediate neighbors in line and be slapped by their neighbors. Students will be asked to practice to count seconds exactly. Now, let’s play the Slappy Game!

Line Formation 1: Model of “Axon”

Procedure. The procedure for line formation 1 is as follows:
1. Students make two lines, as shown in Fig. 2. The distance between adjacent students is ~1 ft. The gap between two lines is longer than a student’s reach.
2. The tutor slaps the shoulder of the first student in the first line.
3. The student whose shoulder was slapped must immediately slap the shoulders of his/her adjacent neighbors with both hands simultaneously, and count 1 s. The process of slapping (from being slapped by his/her neighbor to the impact on his/her neighbors) should take 1 s.
4. The last student of the line must shout “Hey!” when slapped. Then the first student of the next line who has heard “Hey!” will immediately slap the shoulder of his/her adjacent neighbor with his/her hand.

Explanations. The explanation for line formation 1 is as follows:
1. A line of students is a model of the “axon.”
2. A slap by a tutor corresponds to “exogenous stimulation” to the initial segment of the axon.
3. Slaps by students correspond to “electric currents” caused by an action potential in axon.
4. Students cannot slap neighbors during their slapping, as well as for 1 s immediately after their slapping, even if they are slapped by the neighbors or the tutor.

4.1. A student who is slapping (gray gloomy character) is a model of the “absolute refractory period.”
4.2. A student immediately after slapping (white gloomy character) is a model of the “relative refractory period.”

5. Responses are not related to the strength of slapping, i.e., the model of the “all-or-none law.”

6. The last student of the first line shouts “Hey!” if slapped. His/her shout corresponds to “synaptic transmitter release.”

7. The first person of the second line is a listener who listens to “Hey!” His/her listening to the shouter’s “Hey!” corresponds to the “binding of synaptic transmitters to receptors.”

8. If a student at the middle of the second line is slapped by the tutor as a model of “exogenous stimulation” of nerves, a relay of slapping moves toward the shouter, demonstrating “orthodromic conduction,” and a relay moves toward the listener, indicating “antidromic conduction.” A relay of slapping will stop at the listener, because the listener cannot shout.

**Line Formation 2: Saltatory Conduction**

**Procedure.** The procedure for line formation 2 is as follows:

1. Students make one line as shown in Fig. 3. The distance between adjacent students is ~1 ft.
2. Standing and sitting students alternately align. The sitting students are never slapped and cannot slap anybody.
3. The tutor slaps the shoulder of the first student in the line.
4. The standing student whose shoulder was slapped must immediately slap the shoulders of his/her adjacent standing neighbors using a straight ruler in each hand, reaching over the sitting students.
5. The last student of the line must shout “Finish!” when slapped.

**Explanations.** The explanation for line formation 2 is as follows:

1. Standing students are models of “nodes of Ranvier,” and sitting students are models of “parts of the membrane covered by the myelin sheath.”
2. The “jumping” of depolarization from node to node imitated in line formation 2 is called “saltatory conduction.”

3. Measure the conduction time from the tutor’s slapping to the shout of the last student. Compare the conduction time between standard line formation 2 and standing line formation 2 (see no. 3.2, below) to observe and appreciate the swiftness of saltatory conduction.

3.1. Standard line formation 2.
3.2. Standing line formation 2: All students stand and participate in a game without anything in their hands (optional).

4. The tutor can declare “no refractory period allowed” in standing line formation 2. Once the refractory period is banned, students will experience endless slapping until the tutor orders the slapping to stop. This is a model for continuous excitation of neurons (optional).

Statistics

The proportion of students who gave a correct answer before and after playing the game was statistically tested by Liddell’s exact test for matched pairs (6). A $P$ value $< 0.05$ was considered significant.

RESULTS AND DISCUSSION

Only 1 of the 11 students gave a correct answer before playing the game. Most students did not connect their understanding of an action potential to propagation of an impulse. An example of this lack of connection can be seen in the following incorrect answer, “Because an axon always conducts in either direction, impulses do not pass in one direction even in the natural situation.” After the students played the Slappy Game three times, 9 students out of the 11 gave a correct answer for this phenomenon (two-sided, $P = 0.008$).

Most of the students who previously did not make inference from the knowledge of nerve conduction were informed by playing the Slappy Game. The proportion of students who gave a correct answer was markedly increased after playing the Slappy Game, although the outcomes were preliminary based on a small sample. As Schank paraphrased Descartes’s words, it is thinking that is of value, not the knowledge itself (9). Before implementing the game, the students memorized the answer but forget it after the examination, as Schank clearly stated (9). The students voluntarily engaged in peer teaching and group discussion about the question and the game.
sent. They physically experienced the all-or-none law that the strength of slaps did not change the speed of the relay of slaps. As demonstrated by the two examples of correct answers below, they had an excellent change to think deeply, not just recall the answer.

Examples of correct answers to the question are as follows.

Example 1

The action potential evokes bidirectional electric current, i.e., forward (advancing direction) and backward (opposite direction to the advancing direction). The forward current evoked by the action potential (i.e., impulse) induces a new action potential on the forward section of the axonal membrane. This action potential evokes a forward current and a succeeding action potential on the second forward section. This action repeats to the end of axon. This repeating action is the essentials of the nerve conduction. Contrarily, the backward current evoked by the action potential does not induce a new action potential on the backward section, because this section is in the refractory period in the natural situation where the impulse starts from the axonal section adjacent to the soma. Therefore, impulses pass in one direction in the natural situation.

Example 2

In the natural situation, an impulse starts from the proximal end of the axon. The impulse (i.e., action potential) evokes a forward electric current. This forward current induces a new impulse on the forward section of the axonal membrane. This cycle continues to the distal end of the axon. However, a backward current does not cause a new impulse because of the refractory period after excitation of the membrane in the natural situation.

There were still some unsuccessful students even after playing the game. Some students failed to understand the rules of the game and the meaning of the key concepts, i.e., action potential and refractory period. When one such student had this failure, the relay of slaps was stopped at her. She did not know what to do when slapped and did nothing. Some other students were confined to the knowledge of high school biology, i.e., bidirectional conduction of excitation after exogenous stimulus. Bidirectional conduction was erroneously believed to always occur in nerves. In this situation, the student continued to slap whenever she was slapped, not caring about the refractory period, to try to evoke bidirectional conduction. Her behavior, however, raised the curiosity of her peers to voluntarily try a model of continuous excitation of neurons.

The Slappy Game was a very useful learning tool, at least for our nutrition students, to connect action potential with propagation of impulse. Active learning by playing games can help students to physically understand the physiology of nerves. We would like to study the learning effect of the Slappy Game using a larger sample size in a future study.

ACKNOWLEDGMENTS

We thank our undergraduate advanced nutrition course students for allowing us to devise these games in class.

Present affiliation of A. Konomi: Dept. of Nutritional Sciences, Yasuda Women’s University, 6–13–1 Yasahigashi, Asaminami-ku, Hiroshima 731–0153, Japan.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

A.K. and K.Y. conceived and designed research; A.K. and K.Y. prepared figures; A.K. and K.Y. drafted manuscript; A.K. and K.Y. edited and revised manuscript; A.K. and K.Y. approved final version of manuscript; K.Y. performed experiments; K.Y. analyzed data; K.Y. interpreted results of experiments.

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