Neural Coding and Synaptic Transmission: Participation Exercises for Introductory Psychology

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We present two simulations of neural transmission for use in an Introductory *Psychology class. These simulations illustrate the complex coding properties of a single neuron, especially how excitatory and inhibitory postsynaptic potentials accumulate to produce an action potential. A follow-up exercise, using the framework of the simple children's game Musical Chairs, illustrates synaptic transmission, including the effects of psychoactive drugs at the synapse.*

Introductory Psychology students typically report that the material on physiological psychology is troublesome to master. Part of the problem may be instructors' difficulty in imparting an appreciation of the functioning of one neuron and how that neuron communicates with several other neurons.

There are few exercises that help students visualize and assimilate the fundamentals of neuroscience. Ackil (1986) described a trivia-type board game using physiological terms and concepts. This game may be helpful in motivating students to study, but it is not really a demonstration and thus does not permit students any experience of the workings of the neuron. Hamilton and Knox (1985) described a simulation of the major structures of the nervous system. This simulation captures the operation of the nervous system at a molar level; however, it does not help explain functioning at the neuronal level. Kasschau (1981) offered a simple and effective, but limited, demonstration of neuronal functioning, depicting the relative difference in speed between an action potential and synaptic transmission.

We report herein two additional exercises that involve students in a series of simulations of neuronal processes. The first exercise illustrates how excitatory and inhibitory postsynaptic potentials accumulate to produce an action potential. The second exercise, a follow-up to the first, illustrates chemical transmission at the synapse.

Neural Coding Exercise

Students simulate how the neuron accumulates and decodes inputs to produce an action potential. This exercise demonstrates spatial and temporal summation of graded excitatory and inhibitory postsynaptic potentials, the importance of firing rate, the all-or-none nature of the action potential, and the refractory period. In addition, students can gain an appreciation of the complexity of even the smallest neural network and begin to understand how noise in the system and perturbations at the neuronal level need not affect the output from a higher order system. We introduce the exercise soon after neural functioning has been presented in a regular class session.

We use the exercise in discussion sections (10 to 25 students), although it could also be performed in classes of 30 to 45. Some students' ability to view the proceedings may be restricted in classes larger than 45. The minimum time required is 8 to 10 min. The only materials needed are seven index cards; six cards have the letter *E* in one color ink, and the seventh card has an *I* in a contrasting color. We have found that the following sequence of four cases is optimal.

The Basic Simulation (Excitation Only)

One student acts as the receiving neuron and is stationed at the blackboard facing the class. Six other students, preferably in the front row of the class, represent six input paths. (These students are referred to as *inputs.*) The instructor gives each an *E* index card, thus all inputs in the basic simulation are excitatory. Each of the inputs is instructed to hold up his or her card for 3 s, with a 5-s interval between card flashes (i.e., each trial lasts 8 s; the instructor should stagger the starting times for each of the inputs by about 1 to 2 s). The receiving neuron fires whenever any three cards are visible at the same time; that is, the neuron reaches a firing threshold whenever three cards are simultaneously presented. To represent firing, the receiving neuron turns around and writes "I fire" on the blackboard. This turning away from the inputs mirrors a refractory period, during which time the neuron cannot respond to inputs. The receiving neuron is told to ignore a card that is in the process of going up or down, and the inputs are instructed to make their card presentations crisp. After 1 or 2 min, the instructor ends the simulation, and the class counts the number of times the receiving neuron fired.

Excitation and Inhibition

The second simulation illustrates what happens when inhibition is added. A seventh student with the *I* card joins the inputs of the basic simulation. Whenever the receiving neuron sees the *I* card, he or she must ignore one of the *E* cards that might be visible at the same time. Thus, the receiving neuron would not fire if three *E*s and one *I* were visible at the same moment. However, it would fire if four *E*s were present at the same time as the *I*. The decrease in firing rate should be quite noticeable.

Temporal Summation

Temporal summation refers to the ability of the neuron to make decisions about its own firing rate based on the rates of the incoming input signals. For this simulation, six inputs are all excitatory. Five of the inputs flash their cards for 3 s at 5-s intervals, as in the basic simulation. The sixth input flashes for 3 s with a 3-s interval between signals (each trial is 6 s for this input). The increase in firing rate over that of the basic simulation is fairly dramatic.

Spatial Summation

Spatial summation of graded postsynaptic potentials refers to the neuron's tendency to add together inputs arriving at different locations. Because graded potentials decrease in amplitude with distance, inputs closer to the cell body have a greater effect on the receiving neuron than those farther away. To simulate this, four of the six inputs are in the front of the classroom, and the remaining two are in the rear of the room, separated by several students. (Otherwise, this simulation is the same as the basic simulation in terms of input signal duration and interval.) The students should notice how much more difficult it is to detect the inputs in the rear of the room compared to those in the front. The neuron will occasionally miss one of these inputs, thus failing to reach threshold, resulting in a firing rate that is slower than that of the basic simulation.

As time permits, the instructor may lead the class through additional, more complex simulations. For example, in a variation of the excitation/inhibition simulation, the lone inhibitory input could be shown to have an even greater inhibitory effect by increasing its input rate. Or, a lone inhibitory input in the back of the room can be shown to have very little effect on the firing rate of the receiving neuron.

Effectiveness of the Exercise

To gauge the impact of this exercise on our students, we selected eight discussion sections from a single semester offering of our large Introductory Psychology course. Two instructors were involved; both were experienced graduate students who were responsible for four sections each. Each instructor supervised the simulations in two of their discussion sections and delivered a lecture of about 25 min on the action potential and neural coding to the other two sections. The lectures were generated from the instructor's manual of the text used for the course. One week later, the students in all eight sections who were present the previous week were given an 8-item, multiple-choice quiz on neurophysiology. These items were taken from the same item pool used in actual exams, but they did not duplicate items from the exams given that semester. Four of the items assessed general knowledge about the functions and parts of the neuron and about the action potential. They did not address neural coding. The remaining four items did attempt to tap students' understanding of excitation/inhibition, temporal summation, spatial summation, and firing rates.

The exercise groups performed better than the lecture groups on three of the four items that dealt with coding. The percentage correct for each group (exercise and lecture, respectively) for each item was Item 1, 32% and 26%; Item 2, 68% and 73%; Item 3, 80% and 63%; and Item 4, 71% and 60%. The overall percentages of correct items for each group were 63 for the exercise group and 55 for the lecture group. The total correct scores for the four items were analyzed with an unpaired two-group *t* test. The exercise groups ($M = 2.51$ or 63%) performed better than the lecture groups ($M = 2.21$ or 55%), $t(119) = 1.60$, $p < .06$, one-tailed. Differences between the exercise and lecture groups could have been due to variables other than the exercise–lecture manipulation (e.g., the exercise group may have simply been brighter than the lecture group). Therefore, we also performed a *t* test on the differences between the exercise and lecture groups on the items that were unrelated to coding. On the four such items, the mean correct score was 1.80 for the exercise groups and 1.87 for the lecture groups, not a significant difference, $t(119) = .36$, one-tailed. The data suggest that the exercise produces an effect that is at least as good as a lecture on neural coding (in a way that is probably more fun than a lecture).

Synaptic Transmission Follow-Up Exercise

Once students have a grasp of neural coding, we simulate synaptic transmission. In this exercise, which models the familiar children's game Musical Chairs, students take the role of various drugs and neurotransmitters. They simulate the action of the neurochemicals at the releaser sites of the originating axon and at the receptor sites of the receiving dendrite. Differences among drugs that block reuptake, occupy receptor sites, and mimic the neurotransmitter can be illustrated easily.

Basic Simulation

Place four chairs in the front of the class to represent origin sites of the releasing axon and an equal number of chairs facing them to represent the receptor sites on the receiving dendrite. In the basic simulation, students representing neurotransmitters sit in the axon chairs and, on a signal from the instructor, attempt to occupy the receptor chairs; they must sit completely in the receptor chairs and then attempt to return to the axon chairs (reuptake). The students remain seated except during the short time when they are moving between the two sites. In the basic simulation, attempts to occupy chairs will be successful; however, in later simulations, the presence of drugs might prevent or facilitate the occupation of either the receptor or releaser site. When all of the receptor chairs are occupied by a "neurotransmitter," or a substance that mimics a neurotransmitter, the neuron reaches its firing threshold.

In the basic simulation, the student experiences several basic features of synaptic transmission: (a) the origin of neurotransmitters in the sending neuron, (b) the release of neurotransmitters into the synaptic gap, (c) the stimulation of receptor sites by the neurotransmitters, and (d) the return of the neurotransmitters to the originating points. This last feature—reuptake—is often poorly communicated in introductory texts and lectures. In addition, when other chemicals enter the simulation, the student can gain an appreciation of basic neurotransmission and begin to understand how different drugs affect synaptic transmission. This physiological springboard helps the instructor explain both the effects of substance abuse in later chapters that cover drugs and behavior and the effects of antipsychotic medications when the course turns toward psychopathology and treatment. We offer three examples.

Mimicking the neurotransmitter. The stimulant drug nicotine has effects similar to the neurotransmitter acetylcholine. In the simulation, four students representing the drug nicotine and four students representing the neurotransmitter are available to sit in the receptor chairs. Initially, students representing the drug can stand behind the axon chairs. At the instructor's signal to release the neurotransmitter, both the neurotransmitter and the drug students will attempt to occupy the receptor site chairs, quickly filling them. With reuptake, the neurotransmitter students must return to the axon chairs, but the drug students will be present to continue occupation of the receptor chairs, that is, to continue stimulation.

Occupying receptor sites. The class of medications used to treat schizophrenia have their major effects by occupying the receptor sites that dopamine normally occupies. In schizophrenics, receptor sites are thought to be too sensitive to dopamine, thus, practically speaking, there is an excess of dopamine in these patients. By blocking the receptor sites, antipsychotic drugs prevent dopamine from contributing to the initiation of the postsynaptic potential. The blocking of dopamine, therefore, tends to relieve psychotic symptoms. In the simulation, at the instructor's signal, both the students representing neurotransmitter and those representing antipsychotic drugs are released into the synaptic gap to sit in the receptor chairs. To distinguish blocking agents (e.g., in this simulation) from the mimicking agents (e.g., as in the previous simulation), the blocking agents will begin the exercise behind the receptor chairs instead of behind the axon chairs. Initially, the advantage will go to the neurotransmitter students, but as they return to the axon chairs, some receptor chairs will be occupied by the students who represent antipsychotic drugs, thus preventing the neurotransmitter students from sitting in a receptor chair following the next release of neurotransmitter. Neurotransmitter students who do not contact a receptor site because a receptor blocker is sitting in the receptor chair must return, through reuptake, to an axon chair to be released again. We usually mention the other ramifications of the dopamine phenomenon: Antipsychotic medications can block transmissions unrelated to the psychotic disturbance, resulting in Parkinson's-like symptoms; and patients with Parkinson's disease are often treated with the dopamine precursor, L-dopa.

Blocking reuptake. Some antidepressant drugs prevent the neurotransmitter norepinephrine from returning to the releasing axon, thus leaving more of the neurotransmitter in the synaptic gap. This effect is desirable because one of the biochemical problems in psychotic depression is not enough norepinephrine. In the simulation, four students representing antidepressant drugs occupy the releasing site chairs of norepinephrine after the latter have been released into the gap. The four students representing the neurotransmitter, because they must sit somewhere, will continue to occupy and reoccupy the receptor sites, increasing the neurotransmitter's impact on the receiving neuron.

Each simulation takes less than 3 to 4 min. During the first 2 to 3 min, student participants are assigned their roles; the remaining 1 min or so of actual simulation is sufficient to make the appropriate points. We have found that students participating in the exercise and those observing it are able to remember which students are neurotransmitters and which have some other role—the initial 2- to 3-min setup, if done carefully, tends to make this clear. However, some instructors may find it helpful to have students hold cards that identify the roles.

Beyond these basic simulations, the instructor can introduce complexity by combining drugs, placing inert substances into the system, considering the role of enzymatic degradation (e.g., by having some enzyme students "grab" neurotransmitter students, removing them from the synapse), and considering the more complex actions of some drugs. Cocaine, for example, stimulates the release of norepinephrine and inhibits its reuptake. Amphetamines stimulate the release of norepinephrine, mimic norepinephrine, and block reuptake.

Conclusion

The data we collected support our impressions that the neural-coding exercise improves students' understanding of the complexity of coding. Because the synaptic transmission follow-up exercise is used optionally, depending on time availability, we have no formal data on its effectiveness. However, anecdotal reports from our discussion instructors over several semesters suggest that it helps make concrete the often abstract presentations of synaptic transmission in textbooks.

For both exercises, students (and sometimes instructors) often report that they feel silly playing their roles. We tell them that feeling silly is appropriate and acceptable if an understanding of neural functioning results.

References

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Notes

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Using Feature Films to Teach Social Development

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To promote understanding of children's social development during middle childhood, students select, view, and analyze a feature film using theory and research from the course. Students write papers analyzing the protagonist's social development, focusing on peer relations and friendship issues. The quality of these papers and student evaluations demonstrate that this assignment is a valuable educational experience. The exercise enriches students' understanding of course content and fosters a more sophisticated perspective on movies about children. Instructors can modify this technique for other developmental topics.

Psychology instructors have used feature films to foster students' learning (e.g., Bolt, 1976; Dorris & Ducey, 1978; Kinney, 1975). More recently, Fleming, Piedmont, and Hiam (1990) discussed the effective use of film in a course on psychopathology, and Anderson (1992) described the value of film in a course on psychology and law. These authors described many values of film in psychology classes. Students responded positively to the films, perhaps because they offer entertaining, concrete examples of course topics. Students also seemed to become engaged directly with film themes, thereby becoming more involved with course content (Fleming et al., 1990). Film may also improve students' critical thinking and perspectives (Anderson, 1992).

For several years I have used feature films, mostly European, in an undergraduate course, Middle Childhood, covering development during the elementary school years. European films were emphasized because they capture children's experiences and development more genuinely than do American films. The major purpose of the assignment was to elucidate social development topics that we studied in the course via scientific research and theory.

The Film Analysis Assignment

The timeline for this assignment spans several classes (about 2 weeks) during coverage of social development and peer relations. Students complete the assignment during the latter portion of this coverage. During this time, students continue to learn about social development through lecture, readings, and educational films. Sources that I present in class and assign in readings include those by Buhrmester and Furman (1987); Dodge (1983); Hartup (1983); Thorne (1986); and Zarbatany, Hartman, and Rankin (1990).

Students select a film from a list I provide. They watch the movie at home, usually over a weekend, for several reasons. Showing a film in class would require excessive time and would allow students to watch only one film for the assignment. The take-home assignment allows students to watch a film of their own choice, probably one they had not yet seen. Home viewing also allows the luxury of watching the film or certain scenes more than once, which could help students better understand how theory and research are exemplified by the character's experience (Anderson, 1992). Although a film rental may pose logistical problems for some students (e.g., those not owning a videocassette recorder), students may watch a movie with a classmate, sharing the costs and equipment. Students are also encouraged to contact local libraries, which often have varied and inexpensive movie selections.

After watching the movie, students write an essay (of two to four pages), analyzing some aspects of the film characters' social development. Students are instructed to "use the psychological theory and research from the course as a framework in which to understand the social development of the children in the movie." Students are told to "make connections between the characters and their experiences with ideas we have read or discussed in class." Students write their essay in about 1 week and submit it around the time I finish the topic.

To facilitate their analysis, students are given the following questions on a handout: (a) How does the film capture the way a child's peer group makes up a subculture or "society of children"? How does the child's experience in this society differ from his or her experience with adults? (b) How does the film illustrate psychological benefits of having friends and being in a peer group? Conversely, how does the film