USING SIMPLE ANIMATIONS IN PHYSIOLOGY TEACHING: VENTILATORY PATTERNS
A CASE IN POINT

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Constructing diagrams to explain certain physiological concepts can be challenging. There is a whole class of physiological topics, represented here by the neural generation of respiratory rhythm, that are best taught using "dynamic diagrams," a series of diagrams generated through simple animations and based on user-provided inputs. The theory of neural generation of respiratory rhythm discussed here is not necessarily correct or widely accepted. It continues to find a place, however, in some of the most widely read textbooks of physiology, which obligates the teacher to devise effective methods of putting it across to the students. Selected criteria can be defined for identifying areas in which dynamic diagrams would be effective as a teaching tool. Unlike those animations that are used to provide a debatable alternative to wet laboratory, dynamic diagrams explaining certain theoretical concepts should have few rivals.


Key words: algorithm; computer-assisted instruction; graphic animation; block diagram; respiratory rhythm

The use of diagrams in the teaching of physiology is a time-honored method, and often, the success of a teacher depends in large measure on the lucidity of the diagrams he or she provides. Several topics in physiology are better explained through figures and graphs than through elaborate explanations in words. Sometimes a series of figures may be required to explain a concept, examples of which can be found in the countercurrent multiplier mechanism (3) or the genesis of membrane potential (8). If the series is large, it may not be feasible to depict all the stages in perfect continuity. A convenient medium for sequentially illustrating a large array of figures is the computer. These diagrams can be tailored to user-provided inputs using simple algorithms, embellished with animations and displayed in quick succession, resulting in what may be called "dynamic diagrams," a term borrowed from Maw et al. (6). For example, a simple algorithm can generate the numeric figures depicting the sequential changes in osmolarity in the loop of Henle and display them graphically as dynamic diagrams through the computer. Rudimentary animations may be used to depict the flow of tubular fluid. Similarly, dynamic diagrams can depict the sequential changes that lead to the development of membrane potential, with animations showing transmembrane ionic movements (8). When the diagrams are contingent on multiple variables, dynamic diagrams based on interactive computer programs have a significant advantage over conventional diagrams.

In certain cases, however, dynamic diagrams may provide the only effective solution to the construction of a diagrammatic support to a discourse, as I discovered while teaching brain stem ventilatory control. Trying to clarify the basic concepts of the chapter, I
felt that they eluded elucidation through conventional diagrams and, as such, could only be “visualized” mentally. However, many students are not adept at mental imagery, and they find it difficult to understand concepts that cannot be presented visually through figures. Although the neural substrates of ventilatory control could be easily illustrated, the breathing patterns emerging therefrom had to be reasoned out and visualized mentally. The mechanism of ventilatory control as summarized in a popular textbook of physiology (1) is given in THEORY. The accuracy of the model is not the point of contention here; what is noteworthy is how conventional diagrams prove inadequate in elucidating the model. It may not be out of place to mention here that the textbooks referred to in this paper are in wide use in the 150-odd medical colleges in India. Because few physiology teachers in this country have access to the latest scientific literature through journals or the Internet, these textbooks hold sway as the only reliable source of scientific knowledge available to most.

**THEORY**

Signals from the central and peripheral chemoreceptors impinge on a pool of inspiratory neurons (pool A; dorsal motor group). These neurons project to the spinal motor neurons involved with breathing and increase their activity (induce inspiratory muscle contraction). Indeed, the time course of the increase in activity resembles that of the changes in tidal volume. Increased input from various chemoreceptors also increases the neural activity.

The central inspiratory activity stimulates another pool of neurons (pool B; ventral motor group), probably also in the nucleus tractus solitarii. In addition, pool B receives signals from pulmonary stretch receptors. As the lung expands, the stretch receptor signals increase and are added to the pool input.

Pool B, in turn, activates pool C, called the “inspiratory cutoff switch” because its output inhibits the main inspiratory neurons in pool A. When a critical level of excitation occurs in pool C, the activity of pool A is extinguished and expiration occurs. An increase in chemoreceptor activity raises the cutoff switch threshold and enhances central inspiratory activity. Ablation of the pneumotaxic center in the pons also raises the cutoff switch threshold (Fig. 1).

**THE PROBLEM**

Presented as above, the neuronal substrates of ventilatory control should not be difficult to understand. However, the derivation of the resultant ventilatory patterns does pose some problems. Most students did not find it easy to visualize the different ventilatory patterns resulting from the aforementioned neuronal pools, their interconnections, and their different activity states. Nor was I, for some years, able to suggest to the students a simple method for deducing them. I would only exhort them to “reason it out” or “visualize it,” reassuring them that it wasn’t difficult. It was, however, difficult to most of them, as I knew when in the tests, most of them would fall back upon an older model of ventilatory control (5), something that I had not taught but that they ostensibly found easier to understand and remember (Fig. 2). Obviously, it did not tax their imagination much to deduce, for example, that because the apneustic center facilitates the inspiratory center, its stimulation increases the tidal volume.

![Neural substrates of breathing and emergent ventilatory patterns: causal mechanisms not apparent. A–C, pools of neurons.](image-url)
Sensing the problem, I first started employing a block diagram à la Guyton (4, 7), attempting to synthesize a graphic form of the basic ventilatory pattern from the graphs interrelating the discharges of the various neuronal pools (Fig. 3). However, I was conscious that although the diagram did give some visual cues regarding the genesis of the ventilatory pattern and thereby could help a student gather his or her thoughts, the approach did not directly indicate the ventilatory pattern resulting from a variety of combinations of neuronal discharges.

**DYNAMIC DIAGRAMS**

In trying to devise a tool for problem-based graphic depiction of ventilatory patterns, I wrote a program in BASIC to generate dynamic diagrams. The program depicted the discharge of the various neuronal pools at user-suggested frequencies and the resultant ventilatory pattern. The graphics (Fig. 4) generated from the algorithm can be summarized as follows.

Neuronal discharge is depicted through animation, by a short cross line flitting along the neuron. Every time an excitatory ending (from inspiratory center Rα, pneumotaxic center, higher cortical center, or vagus) discharges, a horizontal line (1 pixel thick) is added to the central box (the ventrolateral nucleus tractus solitarii) to depict the summation of depolarization. Conversely, when the inhibitory apneustic center discharges, a line is deleted from the box, lowering the level of the shaded area. Each second (indicated at the lower left corner of the screen; not real time), the various centers discharge sequentially (inspiratory center, vagus, apneustic center, in that order).

The number of times each center discharges is given in the circle alongside (default or user provided; both arbitrary). The discharge frequencies of the apneustic, pneumotaxic, and cortical centers do not change with time. The discharge frequency of the inspiratory center increases every second, the step (ramp) being user provided (default is 0.5). The diaphragmatic
Dynamic diagrams. Respiratory rate (RR) and tidal volume (TV) in the spiogram vary with discharge frequencies (user suggested). The causal link between the neural substrates and a variety of ventilatory patterns is filled in by animations depicting discharge of neurons and summation of potentials. A: normal breathing (with default values of discharge frequencies). B: deep and slow breathing (cortical and pneumotaxic centers not discharging). C: apneustic breathing (cortical, pneumotaxic, and vagal discharges eliminated). D: deep and fast breathing (inspiratory ramp discharge increased). UMN, upper motor neuron; LMN, lower motor neuron.
movement, the tidal volume, and the plot on the spirogram are linked directly to the inspiratory center discharge frequency through convenient (manipulated) proportionality constants. The frequency of vagal discharge increases exponentially after tidal volume exceeds 1 liter.

When the central box gets fully shaded, the expiratory neuron (Rß) is shown to discharge. The diaphragm rises back to resting position, the spirogram plot returns to baseline at a constant rate, the central box gets completely unshaded, and the time counter resets to zero. The whole cycle then begins all over again. Figure 4, A–D, shows the spirograms generated through the program. The logic of the entire program is transparent to the user, and the only things in the program that remain concealed are the proportionality constants that are manipulated to generate realistic values of tidal volume and respiratory rate.

EXPERIENCES

The evaluation of the dynamic diagrams has been rudimentary and essentially anecdotal. My initial experiences with the block diagram were quite disappointing. I used the approach for at least five years with the first-year students in three different medical colleges, where the batches ranged from 100 to 180 students. The lectures were reinforced in discussion sessions in groups of 10–15 students. Because not more than 2–5% of the students in a batch adopted the approach, I reckoned it was not useful. Although I routinely drew (and still draw) the diagram in my lectures, most students reproduced Fig. 1 when asked to describe the brain stem ventilatory control. Even those who referred to Fig. 3 fumbled in viva voce when asked to reason out the consequences of a combination of neuronal activities.

Experiences with dynamic diagrams were by far more encouraging. Because the computer facility in our college is limited, the animation could not be demonstrated to all the students. It was shown only to a group of 15 students (in a batch of 100) on the personal computer in my laboratory during the discussion sessions. Students were fascinated (none of them had seen computer-based tutorials before), and as I demonstrated it to them they enthusiastically urged me to probe all the options offered in the courseware. At the end of the class, they reassured me that they had enjoyed the demonstration and understood it well. Their assurance was matched by their performance in the subsequent test and viva. Interestingly, most of these students (11 of 15) who saw the animation reproduced the block diagram (which I had shown them earlier) in the test that followed. Six students tried to draw the dynamic diagrams (including 2 who drew both). Apparently, the dynamic diagram had helped students understand the concepts, whereas the block diagram provided them with a summary expression of some of those concepts.

CONCLUSIONS

The theory of neural control of breathing discussed here, regardless of its accuracy, provided a pedagogical challenge that could be best addressed through dynamic diagrams. Given the anecdotal nature of the evaluation, it cannot be said with probabilistic confidence whether dynamic diagrams would score over block diagrams in helping out students. What can be said with certainty is that, for the topic discussed here, the dynamic diagrams provide the missing link between the diagram of the “neural substrates” and the spirograms of “respiratory rhythms.” Establishment of this “graphic continuity” is an end in itself in any diagrammatic approach to teaching and should be expected to benefit students unless proven otherwise. The preliminary feedback obtained from students was only on expected lines. A full-fledged experiment to evaluate dynamic diagrams was never intended, and least of all, forms the leitmotif of this paper.

The feedback obtained from the students in a way exposes one limitation of the dynamic diagrams: they are unsuited for the print medium and, for that matter, any medium other than the computer. If the topic in question is to be explained using the paper and pen, block diagrams would probably be the best option left to authors and students alike. Attempts to transpose dynamic diagrams onto the print media may not be quite as successful. For one thing, each dynamic diagram would be equivalent to an unmanageably large series of printed diagrams. Besides, eliminating animations, which are practically irreproducible in print, would render most dynamic diagrams useless.

The topic discussed here has been addressed earlier using a mathematical model. However, the objective and scope of the earlier investigation differed consider-
ably from the approach discussed here. Most significantly, the Ventrol (2) does not display the underlying mathematics to the user, whereas in the model described here, the logic of the algorithm is simple and obvious to the user. Moreover, Ventrol and similar softwares (which also qualify as dynamic diagrams) are designed as alternatives to wet laboratories, whereas the program discussed here is designed for explaining a specific theoretical concept where conventional diagrams prove inadequate.

Several other topics in physiology would yield to effective teaching through dynamic diagrams. The common denominators in such topics would be that a) they are theoretical concepts; b) they cannot be easily demonstrated in totality through laboratory experiments; c) they implicate multiple variables and possibilities; and d) understanding them necessitates working through a series of sequential steps. Similar dynamic diagrams depicting the “neuron as an integrator” could be extended to several other neural networks; indeed, Maw et al. (6) identified spinal circuitry as an area for using dynamic diagrams. Although not essential, the “transparency” of the program logic would obviously enhance the benefits from such diagrams. Dynamic diagrams should be also useful in depicting the cascade effects of disturbing various biochemical equilibria. Work with dynamic diagrams in these areas (as opposed to simulation of laboratory experiments), to the best of my belief, will not go unrewarded.

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