Research Paper E-ISSN No : 2455-295X | Volume : 2 | Issue : 6 | June 2016

ANALYSIS AND METHODOLOGICAL APPROACH TO ADDRESSING THE "MYTH OF THE SODIUM/POTASSIUM PUMP" WHEN TEACHING THE NERVE IMPULSE

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ABSTRACT

This article presents a proposal put forward in a professional development course for graduates and advanced undergraduates of the Biology teacher training course. The course dealt with a frequent problem when teaching Biophysics contents about the molecular mechanism of a nerve action potential in tertiary education. The proposal was based in the Sustainable Cognitive Model of Conscientious Learning (SCMCL). As a starting point, incorrect subordinate concepts were identified that explain inaccurately the responsibility of the sodium and potassium pump in the repolarization of the action potential; as a consequence, strategies and activities were proposed. This allowed them to gain support concepts and new links, with results that were highly satisfactory.

KEYWORDS: action potential, sodium and potassium pump, meaningful learning, sustaining learning, teacher training.

Introduction

Some aspects about the passage of ions through cellular membranes.

Small inorganic ions (such as Na^+, K^+, Ca^{++}y Cl, among others) are water-soluble solute which require transport proteins in order to go through cellular membranes. Among these there are: a- ions channels (they allow the passive transport of ions only); b- the pumps (they allow the active transport of ions); c- the coupled transport (they couple to the passive transport of a solute, the active transport of a second solute).

Ions channels transport highly specified solutes and they allow the passage of 1 to 100 million ions per second. Coupled transports allow the passage of approximately 10 thousand per second, while the pumps allow 100 ions per second. Consequently, the passage of ions through channels is between 10 thousand and 1 million times faster than the passage through pumps.

On the other hand, in a physiological context, the ions channels adopt different configurations called "states". The sodium channels can be opened, inactive or closed, while the potassium channels can be only opened or closed. The only state that allows the passage of ions is the open state, not the closed or inactive ones.

Regarding the "pumps", they are proteins that most of them hydrolyze ATP; therefore, the energy released in the nucleotide hydrolysis allows the passage of small inorganic ions against their electrochemical gradient. There is a particular case present in almost 100% of the animal cells called "sodium and potassium pump", which takes 3 sodium ions out to the extracellular space and enters 2 potassium ions to the intracellular space for every ATP molecule that hydrolyzes. It is scientifically agreed that the physiological relevance of this mechanism of transport lays in maintaining the osmotic balance and volume in the animal cells (Latorre y col., 1996; Píriz N, 2016). However, the sodium and potassium pump has limited involvement in the resting membrane potential (less than 10% of its value) and no involvement in the electrical responses of the cell membrane.

The action potential as the response of the cell membrane

The passage of ions through the cell membranes constitutes a passage of electrical charges per unit of time (Q/ t), as a consequence, it can be considered and measured as an "electric charge". This charge modifies the value of the membrane potential (from now on Vm), defined as the difference between the intracellular and extracellular potential: $Vm = Vi – Ve$. When the value of the Vm varies through time, an electrical response is produced in the cell membrane. The action potential is an electrical response present in excitable cells. In neurons it is produced by Na^+ and K^+ ionic currents. The incoming Na^+ current activates the threshold and it is responsible of the depolarization phase of the action potential (the Vm becomes more positive). Simultaneously, but with a much slower kinetics, the K^+ channels open, which allow an outgoing current of this ion. The inactivation of the former together with an increase of the K^+ current, allow the end of the depolarization and the start of the repolarization (the Vm returns to the resting value) and the hyperpolarization phases (the Vm becomes more negative than the resting value). **(Hille, B., 2001; Cingolani y Houssay, 2006; Latorre y col., 1996; Píriz Giménez N., 2016).**

The myth of the sodium and potassium pump and its methodological analysis

For every ATP molecule that hydrolyzes, the sodium and potassium pump allows the exit of three Na^+ ions and the entrance of two K^+ ions, providing an outgoing cation current which makes the membrane potential more negative. Nevertheless, that contribution to the Vm value is very little (less that 10% of the resting potential). Those who place responsibility for the Na^+ and K^+ pump on the repolarization of the action potential justify their ideas in that during that response, there is a massive incoming of Na^+ to the cell and a massive outgoing of K^+ from it, modifying significantly the concentration of those ions. These hypothetical but incorrect changes would be a "problem" that "solves" the sodium and potassium pump, since it restores the ions concentrations which would occur together with the Vm returning to its resting value. However, in physiological conditions the passage of ions through ions channels does not modify the ions concentrations during an isolated action potential. Since the intensity of a current is measured as the quotient between charge and time (Q/ t), we can infer that even the passage of few ions, as it occurs in a brief period of time, can be a relevant current from a biological standpoint. Moreover, it is worth considering that the changes that the membrane potential (Vm) undergoes are in the order of millivolts (mV). Regarding the nerve cells, in an action potential the Vm value changes approximately in 90 mV (from -60 mV to +30 mV), which from a physics point of view (electric), not biological, is very little. It can be deduced that during an isolated action potential, the sodium intracellular concentration is modified in less than 0.1% (Cingolani, Houssay y col., 1996).

As a result, we consider the fact that during the action potential the sodium and potassium ionic concentrations are not modified, as a central concept which could avoid the incorrect acquisition of it.

This incorrect concept of assigning the responsibility to the potassium and sodium pump in the repolarization of the action potential is a common previous knowledge shared by Biology teachers and students in the teacher training course; therefore it is difficult to change. We consider the concept of "previous knowledge" as "a coherent group of intuitive concepts and ideas, which function according to each person's performance in the real world" (Galagovsky, 2004a). We describe it this way since the presumed change in the sodium and potassium ions concentrations in the intra and extracellular space would be reverted by the action of the sodium and potassium pump during the repolarization of the action potential. That is to say that there would be a problem during the depolarization of the action potential (the change in the ions concentrations previously mentioned) which would be solved with the involvement of the pump during the repolarization.

If we carefully study these incorrect concepts, we will be able to analyze the following underlying ideas:

a) In less than a millisecond (which is the duration of the repolarization phase of the action potential) the sodium and potassium pump could revert the changes in the ions concentrations;

b) In less than a millisecond the sodium and potassium pump could revert the changes in the value of the membrane potential (Vm) determined in the depolarization;

c) The activity of the pump would increase because of the repolarization phase;

d) The activity of the pump can revert, during the repolarization, the effects produced by the ions current between 10 thousand and 1 million times faster, which are responsible of the depolarization.

Identifying these underlying ideas is essential for our proposal.

Summarizing the idea, we can present (Chart 1):

The myth of the sodium and potassium pump
(incorrect Knowledge)
would be a (apparent) solution to:

Problem (not real):
The sodium and potassium ions concentrations are considerably altered during an action potential, if compared to the resting voltage (there is an increase in the intracellular concentration of sodium and the extracellular concentratios of potassium).

Underlying this previous knowledge,
there are the following subordinates concepts:

Evident (clear):
- The incoming of sodium and outgoing of potassium during an action potential transports large amounts of ions

Not evident (not clear):
- The sodium and potassium pump acts fast enough as to revert the ions concentration changes in 1 millisecond.
- The sodium and potassium pump activity can be considerably modified during an action potential

Chart 1. - Methodological analysis of considering the sodium and potassium pump as responsible in an action potential.

Analysis of the problem from the perspective of the Sustainable Cognitive Model of Conscientious Learning and the methodological proposal implemented

Lydia Galagovsky (2004 a) proposed the sustainable cognitive model of conscientious learning (from now on SCMCL) considering 4 essential aspects:

- Difference information (knowledge external to the person), of knowledge (network of concepts and connections within the person). Information turns to knowledge in a sustaining learning process.

- Difference between sustaining learning and isolated learning. In the former, information is integrated as new knowledge to an existing cognitive structure, which is modified since it contains support concept that act as links to the new ones. In isolated learning, the person is not able to link the new concept to his existing cognitive structure; he is only able to memorize it, without connecting it to previous concepts already acquired.

- Difference between "subordinate concepts" and "support concepts". "Ausubel (1968) coined the idea of "subordinate concepts" to explain how new information is connected to other concepts which already exist in our cognitive structure (…) SCMCL presents a new concept called "support concept" to indicate the link between the information that is being processed as new knowledge in sustaining learning. The theoretical difference between subordinate concepts and support concepts lies in the fact that the former can be an incorrect link, while in the latter, it should be correct." (Galagovsky, 2004a, p. 234).

- This model is limited to a conscious cognitive process in an individual whose objective is to learn; it does not consider other multiple factors, such as the affective-motivational, among others.

Regarding the "support concepts", this model states that the greater the number of links created, the more solid and long-lasting the learning will be (Galagovsky L., 2004 a y b). Moreover, it is emphasized the need of making the learner aware of his learning progress regarding the conceptual changes he achieves.

Based on this framework, we present a proposal developed in a professional development course for graduates and advanced undergraduates of the Biology teacher training course, which took place in Instituto de Profesores "Artigas" in 2013. It involved different activities which allowed students to:

1) dismiss the significant changes in the Na^+ and K^+ concentrations during an individual action potential (activity 1);

2) conceptualize that the changes in Vm during an action potential are quick enough as to be produced by ion currents through channels and not pumps (activity 2);

3) understand that the sodium and potassium pump does not modify its activity during an action potential, and that its function involves maintaining the cellular volume, which is coherent with its presence in most of the animal cells and not just the excitable ones (activities 3 and 4).

After finishing each activity, students reflected and reconsidered the description of the molecular mechanism of the nerve action potential, contemplating the changes proposed. An additional activity was planned as closure.

The activities were the following:
Activity 1 (Fig.1)

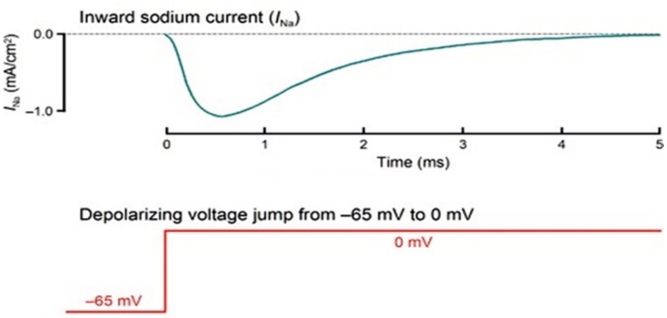

Fig. 1.- Register of a transmembrane current (lower record) using the technique voltage clam (higher record)

Figure 1 shows a register of a transmembrane current (lower record) transported by the Na^+ ion, when the value of the membrane action potential (Vm) is constant (due to the technique called "voltage clamp"), with a value equal to 0 mV.

This current reaches a maximum value in absolute value approximately at 0,5 ms, and then it lowers because the sodium channels are inactivated. Consequently, during the first 2 ms a current is transported which rises and then falls.

a) Assuming that the maximum value reached by the current (we will take the absolute value) is constant during 2 ms. How much electrical charge was transported through a 1 cm^2 membrane during that time? (Remember that I = Q / t, and that 1A = 1C/s).

b) Considering that a mol of Na^+ transports 96500C. How many moles of Na^+ were transported through a 1 cm^2 membrane in 2 ms?

c) Observe the record of a nerve action potential. During the first 2 ms, what happened to the sodium current (I_{na+})? The charge transported by sodium ions during the action potential, will it be lower, higher or the same as the one calculated in b)?

d) The intracellular concentration of sodium ion in a nerve cell is close to 12 mM. Would that concentration change significantly during an action potential? (In order to solve this, it can be assumed a spherical cell whose area is 1 cm^{20}. Therefore, the cell volume will be 0,09 cm^3 (0,09 x 10^{-3} l). Taking into account the number of Na^+ moles transported in 1 cm^2 membrane calculated in b), what will be the change in the concentration of Na^+ in that cell, during an action potential?)

Activity 2 (Fig. 2):

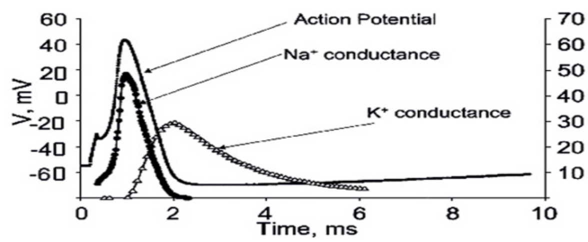

Fig. 2- Changes in the membrane potential (Vm) and the sodium and potassium ionic conductance (Gna and GK) during a nerve action potential.

Figure 2 shows a record of a nerve action potential (full line, ordinate axis on the left signaled with Vm), and ionic conductance curves (dotted line, axis on the right) simultaneous to the action potential.

a) How long does the depolarization phase last?

b) How long does the repolarization phase last?

c) Considering that:

- the ion flow through ion channels is between 106 y 108 ions /s;
- the ion flow through pumps is approximately 10^2 ions/s; and that
- the depolarization is produced by a ion current through channels.

ci) If we represent the ion current transported by the pump with a vector 1 mm thick, maintaining the scale: how thick should the new vector be that represents the ion current transported by the channel?

cii) What type of ionic transport system should be the one responsible for the repolarization phase of the action potential?

Activity 3: Regarding the Na+/K+ pump, it is known that most animal cells have them in their cytoplasmic membranes. Concerning this transporter:

a) How is it activated?

b) Does it modify its activity during an action potential?

c) Does it modify its activity due to a depolarization?

Activity 4: Search in the bibliography and discuss with your partners, what is: - Donnan equilibrium; - Donnan relationship; - cell volume maintenance and regulation; - the pump-leak hypothesis

Additional activity

In order to accomplish a higher number of links (Galagovsky, 2004a), we proposed analyzing the animation Neuron, available in http://phet.colorado.edu/en/simulation/neuron. This simulates the molecular changes that occur in the membrane of an axon during its depolarization, which is represented together with an action potential. It is an easy and engaging animation, which has two considerable advantages: it does not include in the membrane of the axon the Na+ and K+ pump; and it shows the Na+ y K+ ion concentrations before and after the generation of an action potential, making it possible for students to verified the negligible changes in those concentrations during an action potential.

Results

The methodological approach allowed students to:

- Compare the magnitudes of the ion charges through the channels with the ion currents through the pumps; and infer that at the same time, the last ones cannot reverse the effect of the first ones.
- Verified through simple calculation that, in physiological conditions, the ion concentrations are not modified in a cell during an isolated action potential, since the amount of charge transported through the cell membrane is low.
- Understand that, in physiological conditions, the activity of the potassium and sodium pump does not change during an action potential; therefore its activity cannot reverse the electric change in the cell membranes.
- Analyze the changes that were introduced in their productions after each activity, contributing to metacognition.

Conclusions

Not only teachers, but also students who participated in the professional development course, evaluated the proposal based on the sustainable cognitive model of conscientious learning as highly positive. The class observations allowed us to verify that the activities proposed are suitable strategies to deal with previous ideas and build new support concepts and links. Moreover, reflecting about their own learning is especially interesting for graduates and undergraduates of the teacher training course.

Acknowledgments

To the Mag. Silvia Umpierrez, who during her coordination with the Biology Department, managed the support and financing of the UDEBIOP (Unidad de Enseñanza de la Biofísica para la formación del Profesorado) by the Consejo de Formación en Educación (Education Training Council), under which this work was done.

REFERENCES

1. Cingolani, HE y Houssay, AB (2006) Fisiología humana. Buenos Aires: El Ateneo. 7ª edición.
2. Galagovsky, Lydia. (2004a). Del aprendizaje significativo al aprendizaje sustentable. Parte 1: el modelo teórico. Enseñanza de las Ciencias, 22(2), p.229-240.
3. Galagovsky, Lydia (2004b) Del aprendizaje significativo al aprendizaje sustentable. Parte 2: derivaciones comunicacionales y didácticas. Enseñanza de las Ciencias, 22(3), p.349-364.
4. Hille, B. (2001) Ion Channels of Excitable Membranes
5. Latorre R., López Barneo J., Bezanilla F, Llinás R. (eds) (1996). Biofísica y fisiología celular. Sevilla: Universidad de Sevilla. Secretariado de Publicaciones.
6. Píriz Giménez, Nazira (2016) Biofísica para la formación del Profesorado. Montevideo: Ediciones Ciencia, 2ª edición.