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Visualization in neuroscience: a case of cortico-subcortical loops

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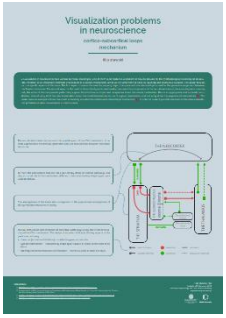

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Abstract

The aim of this paper and poster is to discuss some of the problems occurring in attempts to visualize neurobiological mechanisms. According to the thesis, neurobiological, static schemas should not only depict the order of connections among individual neural structures accordingly, but they have also the potential to present more detailed information about relations within mechanisms, such as patterns of dynamic interactions, their intensity, arrangement and the size of specific components, etc. First I will introduce the problems of visualization in neuroscience, then I am going to discuss these problems with an example of the cortico-subcortical loops (C-SL) mechanism. Finally, I will show my solutions to some visualization problems and discuss the original schemas presented in the poster.

Keywords: visualization in neuroscience; cortico-subcortical loops; philosophy of neuroscience; mechanistic explanation; cognitive processes

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1. Introduction

The aim of this paper and poster is to discuss some of the problems occurring in attempts to visualize neurobiological mechanisms. By visualization, I do not mean either neuroimaging techniques or complex 3D moving models of the brain. I will rather focus on static schemas of neurobiological mechanisms that are usually used in handbooks or scientific articles. According to the thesis of this paper, neurobiological schemas should not only depict the order of connections among individual neural structures accordingly, but they have also the potential to present more detailed information about relations within mechanisms, such as patterns of dynamic interactions, their intensity, arrangement and the size of specific components, etc. Hence philosophy of science (or, more precisely, philosophy of neuroscience) could benefit significantly from developing techniques of graphic visualization in neuroscience – especially in the context of the concept of mechanistic explanation, elevating the importance of graphical representation of the mechanisms.

The mechanistic account of explanation is a common strategy in disciplines such as biology, and in recent years also cognitive science (Boone and Piccinini, 2016). According to this perspective, explaining specific phenomena relies on describing the mechanisms responsible for their occurrence. Usually, it happens in several following steps: (1) localizing the mechanism (2) decomposing its components (3) explaining the interaction between its parts (Bechtel and Richardson, 2010). Mechanistic explanation takes into consideration all explanatorily relevant components and actions of the mechanism (Craver, 2007). Schemas and diagrams use shapes and arrows to exhibit spatial relations and structural features of the elements in the specific mechanism. With help of such techniques, diagrams represent the features of mechanisms that are more easily apprehended in visual form rather than verbally (Machamer, Darden and Craver, 2000, p. 8).

Some authors suggest that the mechanistic approach is not appreciated in neuroscience (Miłkowski, Hohol and Nowakowski, 2019). Apparently, neuroscientists use terms such as neural mechanism or mechanism of perception, but do not apply mechanistic explanation consequently (Miłkowski, Hohol and Nowakowski, 2019). According to above-mentioned authors, mechanistic explanation should be causal, should appeal to components of mechanism and their operations, and require explanatory texts to be complete (i.e., contain only causally relevant components). These elements are sometimes neglected in neuroscience studies. For this reason, it is important to enrich the characteristics of neurobiological mechanisms with adequate visualizations.

In order to make these considerations more concise, I am going to discuss the problem of visualization in neuroscience with an example of cortico-subcortical loops (C-SL) mechanism. In the following paragraphs, I will introduce the

main problems of visualization in neuroscience and briefly describe cortical-subcortical loops mechanism. Having done that, I will show my solutions to some visualization problems and discuss the original schemas presented in the poster.

2. The basic problems of visualization in neuroscience

There are various methods that are used in static visualization of neurobiological mechanisms. General mechanisms are sometimes depicted by a schematic image of the brain with accompanying connections indicating interactions with one another. Slightly more complex mechanisms are usually presented as boxes representing specific structures, connected by arrows symbolizing the direction of influence. Such approach, due to its universality and simplicity, will be the subject of this analysis.

Static visualization in neuroscience needs to be accurate (meaning it should reflect as many aspects of a specific mechanism as possible) as well as legible, in order to keep its instructive purpose. It is difficult to reconcile these aspects neglecting the design aspect, hence appropriate and successful visualization should carry all of the vital information about the multidimensional nature of a given mechanism, and not only show the sequence of stimulations. To illustrate this here, I shall distinguish two groups of basic problems related to visualization in neuroscience: firstly, maintaining appropriate size and spatial proportions between the visualized structures, and secondly, static display of their dynamic interactions.

Structural diversity of neurons and synapses, the properties of neurotransmitters, the mutual position of individual structures and their size are all features significantly affecting the work of the neurobiological mechanism as a whole (Jaśkowski, 2009). Thus, the diagrams showing only the order of the components performing a given function lose an important perspective about the whole mechanism. A visualization reflecting the approximate sizes of individual structures, their spatial position, and the distance between them, provides additional information about the whole mechanism. For instance, it allows us to draw a conclusion about the influence of potential lesions or disorders of the specific structure on others. At times, it may also allow the recipient to discover properties of the mechanism that the author of the diagram may not have been aware of.

In case of static visualization, however, it is also problematic to present dynamic interactions between specific brain regions. In general, interaction between the brain structures depends on inhibitory and activating neurotransmitters. However, this oversimplification should not be applied to visualization, because for some brain structures the lack of information is also informative and regulates its activity. Moreover, stimulation of one struc-

ture can lead to the inhibition of another, and thus sometimes inhibition is reached by activation. These non-intuitive dependencies should also be included in the visualization.

3. The mechanism of cortico-subcortical loops

The concept of cortico-subcortical loops provides general explanations of the physiological control of the motor, emotional and cognitive functions (Gorzelańczyk, 2011; Milardi *et al.*, 2019). Cortico-subcortical loops are the neural circuits that links the specific regions of cerebral cortex, the thalamus and the basal ganglia (foremost the striatum) (Alexander, DeLong and Strick, 1986; Graybiel and Mink, 2009) via two main pathways. The first one – direct pathway – is an excitatory connection that links the cortex and the basal ganglia via the globus pallidus pars externa, and the second one is indirect pathway that inhibits activity of the cortex, and connects cortical regions with the basal ganglia through the globus pallidus pars interna and the subthalamic nucleus (Alexander and Crutcher, 1990; Mink, 1999). The evidence of the empirical data supported by clinical observations and theoretical models suggests there are at least five loops (Alexander, DeLong and Strick, 1986), but this division as well as the functions assigned to the individual loop is rather a conceptual separation, which does not reflect the real structure and complexity of the functions controlling these loops (Gorzelańczyk, 2011).

Originally, it was assumed that these structures control voluntary movements, but subsequent empirical research points out that cortico-subcortical loops do not only activate motor areas of the cerebral cortex. Clinical and neuropsychological data confirm that CS-L are responsible for the control of the majority of motor, emotional and cognitive functions like executive functions, memory, decision making, self-consciousness etc. (Graybiel, 1997; Graybiel and Mink, 2009; Leisman, Braun-Benjamin and Melillo, 2014; Riva, Taddei and Bulgheroni, 2018). The processing of information necessary to manage all of the mentioned functions is hierarchical and occurs simultaneously in various structures of the brain, but the high degree of integration of individual loops indicates that motor, emotional and cognitive functions are inseparable (Gorzelańczyk, 2011). This view is supported by anatomical data as well as clinical observations (Middleton and Strick, 2000; Graybiel and Mink, 2009; Crittenden and Graybiel, 2011). These conclusions are compatible with the assumptions of the embodiment cognition idea, which asserts that the bodily motor functions are closely related to cognitive processes (Gallagher, 2005).

4. Crtico-subcortical loops mechanism's visualization

The poster presents an original visualization of the C-SL mechanism with a proposal to solve the above-mentioned problems relating visualization. It is worth mentioning that the C-SL elements are not anatomically isolated from other areas of the brain (among others, they are regulated by the amygdala, the hippocampus, the claustrum or the cerebellum (Sabatino *et al.*, 1986; Crick and Koch, 2005; Postuma and Dagher, 2006; Hanssen *et al.*, 2019)). Activities and entities constituting the C-SL mechanism have been identified and individuated by their functional roles. This procedure depends on conceptual purposes and hence is up to some point arbitral. The schema was prepared based on the descriptions, visualization available in mentioned literature, Netter's Atlas of Neuroscience (Felten and Shetty, 2012), and three-dimensional, interactive brain model available on brainfacts.org. Let me summarize the schema presented in the poster in a few points:

- The visualization takes into account the spatial aspect of the C-SL mechanism. It reflects approximate hierarchical, geometric and size relationships between individual structures.
- The arrangement of the boxes also corresponds to the approximate arrangement of the symbolized structures in reality.
- Mutual stimulation and inhibition of individual parts plays a key role in the functioning of the C-SL mechanism. The design of an arrow indicates the key aspects of the particular pathway:
    - character (activation/inhibition) – marked in green or red color
    - type (direct/indirect) – indicated by shape type (square or circle) at the start of the arrow
    - intensity (influence/reduction of influence) – marked as solid or dash line style.
- To mark the connections that are not a part of any direct or indirect pathways, but play a crucial role in the mechanism, different colors and starting shape types were used on arrows.
- It reduces the amount of data in the diagram and maintains its transparency.

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