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Editoriale

Memory and Cerebellum

Daniele Gatti[1], *Tomaso Vecchi*[1,2]

[1]Department of Brain and Behavioral Sciences, University of Pavia, Italy; [2]Cognitive Psychology Unit, IRCCS C. Mondino Foundation

Memory is one of the most studied topics in cognitive psychology. Attention to memory has branching out to various domains such as neurobiology, artificial intelligence, and, more recently, neuroscience. Several models have been developed to explain how memory works, some of which, such as those based upon the distinction between short-term or long-term memory have found a place in the collective imagination and have promoted an extremely effective terminology within both the scientific and the popular literatures. Generally speaking, we can define memory as the ability to retrieve information, but this definition does not account either for the fact that this information is continuously changed, modified, or for the lack of a precise correspondence between what is originally encoded and what is later retrieved. At this point, we could ask ourselves: *is memory a memory system? Is the purpose of memory to remember?*

Indeed, the fact that by using memory we can remember information does not necessarily imply that the final purpose of memory is to remember. Surprisingly, this idea has several theoretical problems, first of all the fact that human memory, under normal conditions, makes a great number of "errors": it does not store information as it was perceived or processed, but it transforms them in order to maintain reduced, but more useful and updated information. Several studies have shown that the retrieval of long-term memories involves *active* rather than *passive* reproduction. That is, humans use their semantic knowledge to encode, store and remember information, generally adapting it to their own expectations, with systematic errors that may occur when the same individuals have to retrieve the presented material. We tend to forget the precise features of the information memorized in favor of an extraction of its meaning. Memory makes errors, a good memory makes errors, and it would be extremely difficult to explain, either phylogenetically or ontogenetically, the development of a memory system making so many errors. Both nature and nurture effects converge to define memory as a function that, under normal circumstances, modify and transform our memories because this is what the system is for. We all need memories to be continuously updated in order to be as useful as possible in our everyday life.

Overall, it is possible to conceive memory as a system continuously integrating new and old information in a never-ending process of transforming human memories: the purpose of memory is to predict the future. This hypothesis is largely supported by behavioral and neuroimaging evidence and implies that human memory should be investigated as a system that evolved in order to predict what is going to happen, rather than to maintain what already occurred. Within this framework, the role of the neural areas involved in predictive processes is crucial. In particular, while almost each brain area has been linked to predictive functions, the cerebellum, given its anatomo-physiological characteristics, should be considered as the principal hub of the predictive brain.

The cerebellum is an impressive neural machine: the cerebellar cortex has four times more neurons than the cerebral cortex and is widely connected to the supratentorial areas, mostly with frontal and prefrontal

cortices. Overall, around 70% of human neurons are in the cerebellum and their connections clearly indicate that motor functions are quite marginal in cerebellar activity and functions. Furthermore, it seems unlikely that the 70% of human neurons – around 100 billion neurons – are exclusively involved in motor functions. So, *what cerebellum is for?* In our view, all available data converge to point to the cerebellum as the key structure of a memory system that has prediction as a major role in human cognition.

Cerebellar involvement in cognitive and motor functions would consist in the execution of one same basic function. This hypothesis, called *dysmetria of thought* is supported by cerebellar cortical uniformity and by the existence of extensive cerebro-cerebellar connections. In general, several basic functions have been linked to the cerebellum, such as sequencing, internal models processing, or timing. These concepts can be seen as subunits that are part of a single higher-order process: prediction. This cerebellar involvement can indeed be explained as the processing of a predictive information and, in case of prediction error, as the transformation of the no longer useful memory to better adapt to the environment. Furthermore, on the cognitive side, preliminary neuroimaging and neurostimulation evidence has shown that the same cerebellar areas are involved in retrieval and prediction, thus pointing to a homogeneous memory-as-prediction function from both behavioral and neural points of view.

Going back to our starting point: *Is memory a memory system? Is the purpose of memory to remember?* Although memory can be conceived as a storage, this is continuously changing its content, integrating new information in a continuous process of updating. In order to explain these characteristics, we must change our interpretation of the nature and functions of the memory system. The purpose of memory is not to remember the past but, instead, to predict the future. In turn, the cerebellum could be the keystone merging past experience and future events.

Bibliography

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