Medical Hypotheses (2008) **71**, 61–64

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medical hypotheses

http://intl.elsevierhealth.com/journals/mehy

The role of the basal ganglia in data processing

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Received 4 December 2007; accepted 7 February 2008

Summary Complex cerebral activities are likely to be composed of massively repeated simple data processing tasks since the cortical data processing unit, the cortical mini-column, is found throughout the cortex with only minor variations.

It has been proposed that one task performed by the cortical mini-column may be to match afferent sensory data to learnt datasets in a process known as automatic association. We hypothesize that basal ganglia circuits, through the relative signal of the nigro-striatal and striato-pallidal pathways, determine the matching threshold for dataset matching within cortical mini-columns. Basal ganglia circuits are in a unique position to use parallel information to modulate the parameters of auto-association to increase the speed of data processing tasks. This hypothesis can explain motor symptoms in Parkinson's disease and also predicts that over and underactivity of basal ganglia circuits (the 'on' and 'off' states) will lead to characteristic errors in sensory data interpretation in all modalities — false negative data recognition when 'off' and false positive data recognition when 'on'.

As a preliminary exploration of this hypothesis 16 patients with advanced Parkinson's disease were tested in voice and face recognition when 'off' and 'on'. Each patient exhibited errors in the recognition task according to basal ganglia activity as predicted by our hypothesis. Further experiments to test the hypothesis are proposed.

Introduction

Evidence is accumulating that simple principles of information processing apply throughout the cerebral cortex. First, the entire cerebral cortex is made of one highly preserved and massively repeated unit called the cortical mini-column. Each cortical mini-column is a six layered structure with a diameter of 300–600 μm containing 80–100 neurons [1]. Second, mini-columns in all cortical areas display striking electric similarities. Third, cortical mini-columns are capable of processing any data regardless of the modality by which it was acquired [2,3].

It has been proposed that ''automatic association'' is a universal data processing task performed by the cortical mini-column [4,5]. Automatic association is the process of matching data to datasets which in turn accesses more information. This represents an abstract method of computation that can apply to any type of information processing. A simple example of 'auto-association' is found in using a phonebook. A person's name is used to match against datasets that return an address and phone number [6,7].

Often overlooked by the investigators of cortical mini-column is another highly preserved massively

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0306-9877/$ - see front matter
doi:10.1016/j.mehy.2008.02.013

repeated unit that subserves the cerebral cortex. Basal ganglia thalamo-cortical circuits run from the cortex via the striatum and pallidum through the thalamus and back. These circuits are modality specific but have a strikingly similar structure, suggesting they perform 'a common neuronal process' [8].

Hypothesis

The brain processes massive amounts of information at great speed. If cortical mini-columns are involved in automatic association, the basal ganglia circuits may facilitate this process. In the task of auto association, data is acquired and datasets are present to match the data against. A threshold must exist at which data is considered a match with a given dataset. The speed of auto-association is limited by the rate in which data can be acquired, the rate at which data can be matched against datasets and the threshold at which data is considered a match. If this matching threshold is too low incorrect datasets will be activated. If the threshold is too high data matching will take too long.

The optimum threshold for data matching depends on context. For instance, a small round white object in a nest is more likely to be an egg and less likely to be a golf ball. With contextual information the threshold for matching data against datasets can be reduced thus increasing speed without compromising accuracy. This process can occur independently from matching data to datasets meaning it can be performed simultaneously or 'in parallel'.

Basal ganglia thalamo-cortical circuits are well placed to perform this task. These partially closed circuits modulate a thalamo-cortical signal by the competing input of two pathways, the nigro-striatal pathway and the striato-pallidal pathway [9]. The circuits are arranged in parallel and are known to be important in contextual behaviour [10]. It is proposed that basal ganglia thalamo-cortical circuits modulate the matching threshold for auto-association within the cerebral cortex.

Implications and predictions

The auto-associative model of the basal ganglia may explain motor symptoms in Parkinson's disease. The nigro-striatal pathway becomes under active in Parkinson's disease as a result of dopamine depletion within the midbrain. The most visible symptoms occur in the motor domain with the patient freezing in the middle of movements, becoming rigid and akinetic. This can be altered with dopamine replacement. After five to ten years of treatment 50—100% of patients will develop rapid switching between nigro-striatal under and overactivity. The most apparent symptom of nigro-striatal overactivity is dyskinesia [11].

Movement requires integration of massive amounts of data at very high speeds. To initiate a movement the exact position of large numbers of joints, the status of large numbers of individual muscle fibers and estimates of environmental factors, must be taken into account. To maintain a movement high volumes of data must feed back to allow necessary adjustments [12].

Since the brain initiates a movement, it understands the purpose. If a person wants to move a limb to a new position, the brain decides exactly what muscle fibers to use with what force. It has the necessary context data to predict where the arm should be moving a short time later. The dataset thresholds for arm positions throughout the expected movement can be lowered, allowing less information to be analysed for the movement to occur smoothly.

It is known that in Parkinson's disease bradykinetic movements occur in tiny steps, as opposed to a smooth sequence (such as when a normal person performs a slow movement) [13]. Additionally, Parkinsonian patients experience 'freezing' episodes, where large amplitude complex movements (such as walking) come to a halt and cannot be restarted. This often occurs in the setting of a sudden increase in sensory data input (such as encountering a doorway or obstacle). We propose that in Parkinson's disease, with underactivity of the nigro-striatal pathway (OFF), dynamic reductions in movement dataset thresholds cannot take place. Too much information is necessary to activate the next sequence of movement and the movement stops until enough data can be acquired. The brain is overloaded with data it cannot process fast enough to allow the next phase of a movement to proceed smoothly.

In patients with overactivity of the nigro-striatal pathway (ON), it is proposed datasets are inadvertently activated due to the thresholds being non-specifically set too low. This misleading information may go on to activate unintended sequences of movements leading to dyskinesia.

If the proposed hypothesis is correct, deficits will be present in other domains than movement as the basal ganglia circuits are found all areas of the cerebral cortex. ''Freezing'' and ''dyskinesia'' will have correlates in all cognitive domains, not just motor activity. Nigro-striatal pathway underactivity will