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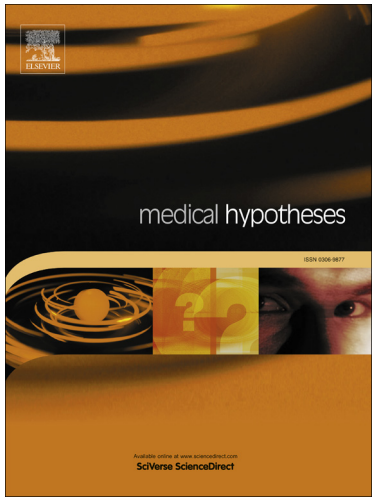

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Aristotle Got it Right Again!

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Aristotle Got it Right Again!

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We would like to draw attention to the interesting implications of the existence of common cerebral networks - demonstrated in several recent meta-analysis studies on time perception[1-3] - to current knowledge of higher cognition processes.

In particular we wish to highlight the results of a juxtaposition of two meta-analyses: a multimodal SDM study to identify brain regions involved in neuroimaging studies of response to increasing levels of cognitive difficulty; and an ALE meta-analysis on neuroimaging of time perception[2]. The former meta-analysis comprised 54 fMRI studies undertaken whilst subjects did tasks requiring executive functions. For the latter meta-analysis, there were 35 fMRI studies that looke d at different aspects of temporal estimation, such as, interval estimation and discrimination of duration. We then used anatomic cerebral coordinates to carry out an overlapping analysis of statistically significant activation patterns from both meta-analyses.

Note that what both groups of studies had in common was that they compared cerebral activation between two levels of difficulty of their respective experimental tasks. The methods and procedures involved are not new, they have been used in hundreds of neuroimaging studies over the last decade with a view to obtaining a functional neuroanatomical map and elucidating the connection between experimental tasks and superior functions. However, the same studies also reflect how the brain responds to an increase in cognitive load, an increase in the difficulty of what is demanded or an increase in the effort required. The fact that all the studies involve this kind of cognitive change is, we believe, critical to the interpretation of our results.

Our main finding was that there is a group of brain regions engaged both by time perception tasks and by tasks involving an increase in cognitive load for non-time related executive functions. There was a high degree of bilateral overlapping of cortical and subcortical regions, but also there were well-defined

regions that did not overlap. That is, the overlapping regions participate in both temporal perception tasks and executive function tasks, whilst the non-overlapping regions were only activated by one of the task types. The bilateral cortical regions that overlapped were specifically the prefrontal and cingulate areas as well as the parietal and temporal (insula) regions (Figure 1).

The results and their interpretation have, we believe, two important implications. First, there are cerebral networks - that we might call *Temporal Networks* or *Cognitive Change Networks;* and second, that these networks sustain and are common to all mental processes and operations that demand increases (and possibly also decreases) in cognitive load.

Another recent meta-analytic study[4] found evidence to support a hypothesized superordinate cognitive control network in the brain subserving diverse executive functions domains. This network involved dorsolateral prefrontal, anterior cingulate, and parietal cortices. On the basis of our study we would concur that these cerebral networks exist but also suggest that the networks respond to changes in the demands made of them. With regard to the regions involved, the meta-analyses coincide, but we found the temporal insula, medial frontal (supplementary motor areas) and basal ganglia were also implied in our *Temporal / Cognitive Change Network.*

These findings shed light on the mechanisms underlying cognition of higher processes. Carrying out any cognitive task, for example, during everyday activity, involves continuous modulation of the level of effort needed to deal with the ever-changing difficulty. In addition to task-specific networks, such changes in cognitive load also require participation of the common cerebral networks whose existence is suggested by these recent studies.

The common networks that support modulation of effort during tasks involving executive functions also support time perception tasks. This finding somewhat belatedly provides backing to Aristotle's philosophical concepts[5] that time perception is related to the perception of change and that time is ubiquitous; just as time is omnipresent in the processes of nature, so are the higher human cognitive functions.

We declare that we have no conflict of interest.

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Figure 1. Footnote
Overlap and lack of overlap between brain regions engaged during time perception tasks and during tasks requiring cognitive effort. (Talairach axial slices in neurological convention (i.e. right is right, left is left) showing regions with statistically significant activation only during time perception tasks (meta-analysis, red), regions with statistically significant activation only during tasks requiring cognitive effort (meta-analysis, blue), and regions with statistically significant activation both during time perception tasks and during tasks requiring cognitive effort (green).
(Radua et al. Neuropsychologia (2014). With permission from Elsevier).

Fig. 1.