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Where in the brain is human intelligence?[☆]

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ABSTRACT

We still know relatively little about how the human brain supports intelligence. I this personal view I argue that adopting the framework of neurocognitive component processes (NCP) might advance the current state of knowledge. Integration of information processing across distributed brain regions is proposed as a potential NCP, and some possible clinical implications of adopting the NCP framework are outlined.

We live in the era of artificial intelligence (AI). This very week of October 2024, while writing this personal view, it was announced that Demis Hassabis and John Jumper were awarded the Nobel prize in Chemistry for their AI model AlphaFold2 that has revolutionized the field of predicting protein structures (they shared the prize with David Baker). It was further announced that John Hopfield and Geoffrey Hinton were awarded the Nobel prize in Physics "for foundational discoveries and inventions that enable machine learning with artificial neural networks". Despite the rapid progress in the field of AI, we still know relatively little about how the human brain supports *human intelligence* (***HI***).

The scientific study of ***HI*** has a long tradition. At least dating back to Spearman in the early 1900′s [1], it has been known that individual differences are correlated across various cognitive domains and abilities, such as reasoning, working memory, long-term memory, speed of processing, spatial ability and more. Hence, an individual with high scores on tests tapping a certain domain will tend to have high scores on tests tapping other domains. This tendency or 'positive manifold' has been viewed as reflecting a general cognitive ability or general intelligence (Spearman's "g"). A more contemporary mainstream scientific definition of intelligence stated that "*Intelligence is a very general capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience* " [2, p.13]. Consistent with the present argument that we still know relatively little about how the human brain supports ***HI*** it was further stated that "*The brain processes underlying intelligence are little understood*" [2, p.14].

The Parieto-Frontal Integration Theory (P-FIT) of intelligence by Jung and Haier [3] has been seen as "the best available answer to the question of where in the brain intelligence resides" [4, p. 207]. P-FIT holds that variations in an extended frontal-parietal brain network are related to individual differences in intelligence test scores. A foundation for the P-FIT was that frontal-parietal regions are commonly engaged during execution of a variety of complex cognitive tests. This is further underscored by observations of frontal-parietal activation during a variety of tasks, such as working- and long-term memory, consciousness, and attention [5–7], which has been conceptualized in terms of a cortical multiple-demand system for intelligent thought and action [5].

In the context of P-FIT, a *component-process approach* might be informative. It has been recognized that complex concepts like cognitive control, executive functions, and working memory likely share underlying neural and cognitive components [8], here referred to as *neurocognitive component processes* (NCPs). NCPs can be seen as basic building blocks that can be combined in various ways to give rise to complex cognition. Some NCPs are triggered by specific task demands (e.g., updating), whereas others are recruited more generally across a range of cognitive tasks. For instance, common fronto-parietal activation during selective attention and working memory tasks could reflect the operation of a shared NCP [9–10].

What might be an NCP for ***HI***? In a commentary to the original P-FIT paper we highlighted the importance of *integration* [11], and Jung and Haier responded:

"*We are inclined to propose that intelligence may be defined as the degree to which the fronto-parietal network integrates and controls the flow of information throughout the brain* " [3, p. 177].

The importance of integration of information processing across

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distributed brain networks is stressed in various theoretical accounts, such as the brain as a selectionist system [12], and integration has been related to concepts such as *reentry* [13] and *binding* [14]. Of particular relevance in the present context, an integration account for how integrated intelligence can emerge from spatially and temporally distributed brain activity has been proposed [15]. Individuals who manage complex cognitive tasks well, so-called more intelligent individuals, are characterized by more efficient network interactions [16,17], and there is evidence that individual differences in network efficiency are shaped by both genetic influences [18] and experience [19].

A crucial issue is how to quantify integration in the brain. Advances in network-based analyses of inter-regional interactions have greatly contributed to this challenge, including whole-brain computational modelling approaches [20]. A recent multimodal and multispecies investigation presented an information-decomposition metric that can quantify integration at the macroscale as information that is derived from regional interactions [21]. Applying this metric to resting-state functional MRI data revealed 'synergistic interactions' in higher-order association areas, which enabled integration of complementary information across brain areas. Synergy was salient in fronto-parietal regions, supporting their role in integration. Synergistic interactions were found to be more salient in the human brain than for nonhuman primates and supported by human-accelerated genes underpinning synaptic function. These and other examples [22] demonstrate how integration can be quantified in the human brain and be related to scores on complex cognitive tasks.

HI is highlighted in various clinical contexts, including in relation to executive functions, brain atrophy and ischemic cerebrovascular disease [23–24], as well as in relation to AD risk [25]. Decomposing ***HI*** into its constituent NCPs may further our understanding of such relations. One particularly relevant example in the present context is that integration has been suggested to account for the impact of brain lesions on the performance on measures of ***HI*** and executive function [26]. More generally, the NCP framework could be relevant in the context of DSM-5′s different neurocognitive domains and the classification of neurocognitive disorders [27]. For instance, if a patient presents with reduced fronto-parietal brain activation and/or deficient performance across several neurocognitive domains (e.g., executive function, complex attention, learning and memory), this could be interpreted as multiple-domain impairment. Alternatively, this pattern could reflect a common NCP dysfunction manifested as inability to integrate information processing across distributed brain regions.

In conclusion, the title of this personal view asked where in the brain is human intelligence. I propose that the answer is in frontal-parietal integration of information processing in distributed brain region at a given time and across time. This proposal builds on past work on the brain-intelligence link, as selectively reviewed above, and on pioneering ideas of how the brain organizes its subsystems to give rise to integrated and intelligent behavior [28]. The perhaps somewhat novel idea is to propose that fronto-parietal integration of distributed processing constitutes a core NCP that is taxed by many cognitive tasks. I hope the NCP perspective will be considered in future DSM versions, and contribute to advancing our understanding of neurocognition and its disorders.

CRediT authorship contribution statement

Lars Nyberg: Writing – original draft, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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