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Fluid intelligence: A multiprocess framework for individual differences, item difficulty, and neural network dynamics

Author: Shokri Kojori, Ehsan

Abstract: The neurocognitive underpinnings of fluid intelligence (or fluid reasoning), the ability to reason in novel conditions, are of high interest. While fluid reasoning has been often considered as a whole, multiple cognitive processes are expected to affect fluid reasoning performance. I present a multiprocess framework for studying individual differences, item difficulty, and neural network dynamics in fluid reasoning. Change detection (CD), rule verification (RV), and rule generation (RG) were the three processes-of-interest, additively recruited in a novel visuospatial reasoning task. Behavioral results showed that individual differences in likelihood of success and speed of each of these processes accounted for different aspects of accuracy and response time variability in fluid reasoning, as measured by Raven's Progressive Matrices. Results also suggested that a multiprocess framework better accounted for fluid reasoning performance variability relative to a capacity-based approach. Neuroimaging results indicated that distinct brain regions contributed to CD, RV, and RG performance. Within the left prefrontal cortex, in particular, there was a dissociation between lateral regions mediating RV and ventral regions mediating RG. Multivariate Granger causality analyses revealed that changes in the inter-process connectivity were consistent with task conditions additively recruiting CD, RV, and RG processes. There was a notable shift in the origin of frontal-to-posterior brain influences, from the caudal-frontal toward the left dorsolateral-prefrontal regions, when rule-based processing was emphasized. The study also informs about the modulation in top-down and bottom-up processing streams between RV and RG processes, respectively. For item difficulty, it was shown that item performance variance can be decomposed into process-specific demand composites. In support of this decomposition, it was shown that brain regions sensitive to item-level demand for CD, RV, and RG processes were similar to those identified by task-level contrasts. Under the presented framework, effective difficulty can be defined as the interaction between item-specific demands and individual's associated abilities. In summary, the multiprocess presentation of fluid reasoning accounts for individual differences in multiple performance constructs, specifies process-specific demands at the item-level, and is effective for characterizing dynamics of brain activity and connectivity. Finally, the findings may have implications for reasoning diagnosis, training, or treatment monitoring applications.

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