A role for the brain network mechanisms of flexible cognitive control in human intelligence

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Evidence suggests working memory capacity contributes substantially to the more complex construct of general fluid intelligence (gF) (Engle, Tuholski, Laughlin, & Conway, 1999). Recently, a more basic cognitive control factor – rapid instructed task learning (RITL) (Cole, Bagic, Kass, & Schneider, 2010) – has been shown to contribute to gF (Duncan, Schramm, Thompson, & Dumontheil, 2012). RITL is the ability to rapidly (i.e., on the first trial) learn novel tasks from instruction, reflecting flexible control of cognition. Importantly, working memory and RITL have recently been tied to specific neural mechanisms. Thus, a new multi-level explanation of human intelligence is emerging, in which basic cognitive control capacities mediate the relationship between gF and neural mechanisms.

Given the likely computational complexity of gF, however, there are likely many neural mechanisms underlying cognitive control and gF. Indeed, evidence is emerging that one of the largest networks in the brain – the fronto-parietal control network – is central to cognitive control and gF (Cole & Schneider, 2007; Jung & Haier, 2007). This network includes approximately a dozen brain regions, each with complex connectivity and activity dynamics.

Critically, progress is being made in understanding how these regions' connectivity and activation contribute to cognitive control and gF. For instance, recent work showed how activity in this network during the N-back working memory task correlates strongly with gF (Burgess, Gray, Conway, & Braver, 2011). More recently, we found that the functional connectivity of one control network region – a portion of lateral prefrontal cortex – with the entire brain correlates strongly with gF (Cole, Yarkoni, Repovs, Anticevic, & Braver, 2012). This accounted for 10% of gF variance ($R^2 = .10$, $p = .004$), which was greater than and statistically independent from brain volume and LPFC activity in the same dataset ($R^2 = .07$ and $R^2 = .05$, respectively). These results suggest gF is partially the result of the ability of lateral prefrontal cortex to communicate with a variety of brain regions, possibly due to its role in regulating activity and connectivity in a goal-directed manner (Miller & Cohen, 2001).

One concern regarding this connectivity result, however, is the possibility that the metric used to estimate brain-wide connectivity – global brain connectivity (GBC) – can reflect within-network connectivity in addition to between-network connectivity. We used two additional graph theoretical measures – participation coefficient and betweenness centrality – to isolate between-network connectivity. We found that lateral prefrontal cortex has among the highest between-network connectivity in the brain, and that gF was predicted by lateral prefrontal cortex's between-network connectivity above and beyond GBC. This supports the conclusion that lateral prefrontal cortex's extensive brain-wide connectivity (as opposed to simply connectivity within the fronto-parietal control network) supports gF. We plan to extend these findings in the future by using intermediate cognitive constructs such as RITL, as they will be essential for understanding the functional role of this and other neural mechanisms in implementing gF.