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Gray matter correlates of fluid, crystallized, and spatial intelligence: Testing the P-FIT model

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ABSTRACT

The parieto-frontal integration theory (P-FIT) nominates several areas distributed throughout the brain as relevant for intelligence. This theory was derived from previously published studies using a variety of both imaging methods and tests of cognitive ability. Here we test this theory in a new sample of young healthy adults (*N* = 100) using a psychometric battery tapping fluid, crystallized, and spatial intelligence factors. High resolution structural MRI scans (3T) were obtained and analyzed with Voxel-based Morphometry (VBM). The main findings are consistent with the P-FIT, supporting the view that general intelligence (*g*) involves multiple cortical areas throughout the brain. Key regions include the dorsolateral prefrontal cortex, Broca's and Wernicke's areas, the somato-sensory association cortex, and the visual association cortex. Further, estimates of crystallized and spatial intelligence with *g* statistically removed, still share several brain areas with general intelligence, but also show some degree of uniqueness.

Individual differences in intelligence result from both genetic and non-genetic factors. Making a key point for the genetic view, Kovas and Plomin (2006) have proposed the "generalist genes hypothesis". This hypothesis states that the expression of genes is distributed throughout the brain, not localized in any discrete region. For the non-genetic view, Garlick (2003) has argued that intelligence differences derive from the development of neural connections in response to environmental challenges.

Genetic and non-genetic factors and their interactions impact brain structure (Draganski et al., 2004; Posthuma et al., 2003; Thompson et al., 2001). Haier and colleagues have shown that variation in structures throughout the brain was related to intelligence (Colom, Jung, & Haier, 2006a,b, 2007; Johnson, Jung, Colom, & Haier, 2008; Haier, Jung, Yeo, Head, & Alkire, 2004, 2005) finding that (1) there are significant associations between brain variations in gray matter (GM) density across discrete areas of the frontal, parietal, temporal, and occipital lobes, and IQ scores, (2) there are pronounced age and sex differences, and (3) the associations are distinguishable for IQ, the *g* factor, and cognitive abilities orthogonal to IQ (Colom, 2007; Johnson et al., 2008). Toga and Thompson (2005, 2007) also have discussed how structural brain mapping could increase our understanding of intelligence.

Recently, Jung and Haier (2007) have proposed the parieto-frontal integration theory (P-FIT) of intelligence after the consideration of 37 neuroimaging studies published between 1988 and 2007. The P-FIT model is consistent with the generalist genes hypothesis mentioned above (Kovas &

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Plomin, 2006), because several regions distributed across the entire cerebral cortex and within discrete white matter regions are identified. These P-FIT regions generally imply distinguishable information processing stages (Fig. 1):

1. In the first stage, temporal and occipital specific areas process sensory information: the extrastriate cortex (Brodmann areas –BAs– 18 and 19) and the fusiform gyrus (BA 37), involved with recognition, imagery and elaboration of visual inputs, as well as the Wernicke's area (BA 22) for analysis and elaboration of syntax of auditory information.
2. The second stage implicates integration and abstraction of this information by parietal BAs 39 (angular gyrus), 40 (supramarginal gyrus), and 7 (superior parietal lobule).
3. In the third stage, these parietal areas interact with the frontal lobes, which serve to problem solve, evaluate, and hypothesis test. Frontal BAs 6, 9, 10, 45, 46, and 47 are underscored by the theoretical model.
4. Finally, the anterior cingulate (BA 32) is implicated for response selection and inhibition of alternative responses, once the best solution is determined in the previous stage.

White matter (WM), especially the arcuate fasciculus, plays a critical role for a reliable communication of information across these brain processing units.

Jung and Haier (2007) posit that not all these brain areas are equally necessary in all individuals for intelligence. They predict that discrete brain regions of the dorsolateral prefrontal cortex (BAs 9, 45, 46, and 47) and the parietal cortex (BAs 7 and 40) may be key for the core of general intelligence.

Whereas the P-FIT stressed the commonalities among studies, Colom (2007) noted the great variability among the studies summarized by Jung and Haier (2007). Only a very small number of discrete brain areas approach 50% of convergence across published studies employing the same neuroimaging strategy: (a) structural studies nominate 32 brain areas, but only BAs 39–40 and 10 approach 50% of convergence; (b) PET studies nominate 22 brain areas, but only BAs 18–19 and 46–47 enjoy 50% of convergence; (c) *f*MRI studies nominate 26 brain areas, but only BAs 6, 9, 7, 40, and 19 reach 50% of convergence.

Why is the evidence so heterogeneous? Most neuroimaging studies of intelligence are limited by small sample sizes, wide age ranges, and a broad variety of individual tests used to assess cognitive abilities (Haier & Jung, 2007). The purpose of the present paper is to test the main aspects of the P-FIT in a new sample of one hundred young healthy participants of both sexes and a small age range using a psychometric battery tapping fluid, crystallized, and spatial intelligence.

1. Method

1.1. Participants

405 university undergraduates were recruited from the *Universidad Autónoma de Madrid* and the *Universidad Complutense de Madrid*. They completed a battery of nine tests measuring intelligence. A sample of 120 Ss was randomly selected for MRI scanning (60 males and 60 females). 104 volunteered to participate in the study, but 4 scans were of insufficient quality for analyses. Therefore, the final sample was comprised of 100 Ss (56 females and 44 males, mean age = 19.9, SD = 1.7, age range = 18 to 27). Ninety three Ss were right-handed.

All Ss gave informed written consent. Participants completed a questionnaire asking for medical, neurological, and psychiatric illness, or conditions that would be contra-indicated for undertaking MRI scans. They received a payment of 20 € for participation.

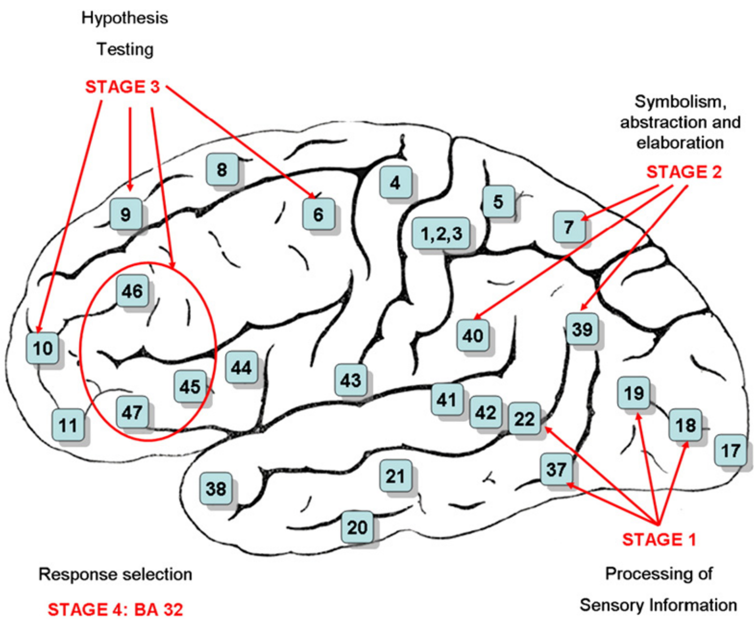

Fig. 1. Processing stages associated with specific brain regions according to the P-FIT model: processing of sensory information (stage 1), symbolism, abstraction, and elaboration (stage 2), hypothesis testing (stage 3), and response selection (stage 4). The arcuate fasciculus (i.e. the neural pathway connecting the posterior part of the temporo-parietal junction with the frontal cortex) is not shown in the figure, but also underscored by the P-FIT model.