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Review

From the earth to the brain ☆

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ABSTRACT

Here I briefly discuss an agenda for increasing our current knowledge regarding human intelligence. This psychological trait is of paramount relevance for understanding behavior in a wide variety of settings. The brain captures the interactions between genes and the environment, and observed individual differences in intelligence result from the way these complex relationships are implemented in this organ. We made some progress in the last decades, but I suggest that we need a strategic change for making a substantial advance. We strongly require an 'Intelligence Program' inspired by past efforts such as the 'Apollo Program'. Scientists interested in human intelligence must make a voyage from the earth to the brain. I suggest this is the only way for moving beyond small steps and for achieving the required giant leap forward.

1. Introduction

1.1. A personal note

I contacted Richard J. Haier almost a decade ago because I began to be interested in brain imaging. We did not have any contact before, but I was looking for a scientist willing to introduce me into the world defined by the interaction between the brain and the intelligence construct. He was a pioneer (Jensen's words) and I was looking for someone with crystal-clear thoughts. He was the chosen one and, fortunately, he said yes to my proposal for visiting the University of California at Irvine.

I learned many interesting things under his supervision (I still do) but perhaps what I remember with the greatest vividness are the evenings at his home watching the HBO TV series '*From the Earth To the Moon*'. The 'Apollo Program' was inspiring for him and the success of this huge project influenced his decision to become a scientist. He (properly) thought I should watch the chapters of this series produced by Tom Hanks during my visit.

Indeed, it was a fantastic idea. I absorbed the bottom line message Rich was trying to provide. Since then I have invested most of my time doing neuroimaging research thought to be relevant for increasing our understanding of the biological basis of the intelligence construct. But now I see that this is not enough. We need more. We strongly require an 'Intelligence Program'. We, scientists interested in human intelligence, must work in tandem and become deeply focused on making an exciting voyage from the earth to the brain. In my view, this is the only way for moving beyond small steps and for achieving the required giant leap forward.

2. Intelligence within the psychological cosmos

There are many psychological traits investigated by scientists interested in human behavior (Ackerman & Heggestad, 1997). There is also a tendency to increase the number of such traits (Gardner, 1999; Kaufman, 2013; Sternberg, 1985). However, these traits can and must be ordered according to their relevance for a proper understanding of behavioral differences.

When we analyze the available data of how traits are related to each other, it is easy to conclude that trait intelligence is particularly relevant (Ackerman, 1996; Deary, Weiss, & Batty, 2010; Schmidt & Hunter, 2004). Intelligence is an integrative trait and, from this perspective, intelligence can be considered the sun of our psychological cosmos. The remaining traits move around. Some are close. Some are far away.

We know that intelligence has to do with our genes and with our brains. Quantitative genetics demonstrates, beyond any reasonable doubts, that we must pay attention to the genes for understanding intelligence differences (Bouchard & McGue, 2003). Brain research also has shown that what intelligence tests measure is related to brain structure and function (Jung & Haier, 2007). As noted by Kovas and Plomin (2006) it is crucial to make an informed trip from the genes to the brain.

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3. From genes to brain structure

Chen et al. (2012), Chen et al. (2013) have published two studies analyzing how genes influence cortical surface area (CSA) and cortical thickness (CT). They found that the brain could be parceled into twelve regions distinguishable on genetic grounds. Interestingly, these regions were related, and, therefore, a hierarchy was identified for both CSA and CT. For the former, a two-cluster solution was based on the division anterior–posterior regions of the brain, whereas for the latter the two-cluster solution was based on the division dorsal–ventral.

These distinctions led to the conclusion that (a) CSA clusters show large genetic proximity with clusters in the same lobe and (b) CT clusters are related according to their maturational timing (primary vs. association cortex). Importantly, the anatomical localization of CSA and CT clusters was almost identical, but their genetic determinants were independent. One of the main conclusions of these two studies is that genes determine cortical regionalization. The authors suggested that any localization changes across the life span should be determined.

The recent study by Karama et al. (2013) is particularly relevant in this respect. These researchers analyzed individuals from the Lothian Birth Cohort 1936 who were tested with the same intelligence test at eleven and seventy years of age. Brain images were obtained when these participants reached 73 years of age. Variations in cortical thickness were correlated with intelligence scores at both time points and the results revealed remarkably similar correlates. Indeed, most of the association between the considered brain index and intelligence measured at 70 years of age was explained by intelligence measured at eleven years of age. This supports a lifelong association between intelligence and cortical thickness. A plausible, if not probable, reason for this is that genes influencing intelligence in childhood are also influencing intelligence in old age. In short, understanding how genes operate at the brain level is likely crucial for understanding brain structural features related with intelligence across the life span.

4. Psychometrics and neuroimaging

Colom, Karama, Jung, and Haier (2010) and Colom and Thompson (2011) have discussed extensively the relevance of using straightforward psychometric approaches to analyze neuroimaging data with respect to the intelligence construct. This is not the place for repeating these arguments, but two key examples will be discussed.

Colom, Jung, and Haier (2006) showed that variations in the *g* loadings of a set of Wechsler's subtests are particularly relevant for the smaller or greater recruitment of gray matter clusters necessary for understanding the measured performance differences. Specifically, increased *g* loadings were parallel to the increased number of gray matter clusters correlating with the individual differences observed in the subtests. Thus, for instance, block design showed a *g* loading of .90, picture completion showed a *g* loading of .60, and digit symbol showed a *g* loading of .20. It was shown that the greater the *g* loading, the larger the number of gray matter clusters correlating with the measured performance. Therefore, *g* loadings show biological substance and are not mere statistical ghosts.

Karama et al. (2011) measured school skills, verbal reasoning, and spatial reasoning in a large sample of healthy children and adolescents. The cortical thickness correlates for these factors were notable and widespread. However, when the *g* component was statistically removed, the residual variance for these three factors (and also for the administered subtests) revealed null cortical thickness correlates. Therefore, finding gray matter correlates for intelligence requires *g*; apparently, there is no intelligent life beyond *g*.

These two studies (see also Román et al., in press) might help to explain the disparate findings that can be found in the literature summarized by the P-FIT model of brain/intelligence relationships (Jung & Haier, 2007). This framework is extremely helpful for organizing the available empirical evidence. However, we must consider the fact that there are substantial differences among published studies, both in the structural and the functional domains (Colom, 2007). The *phenotype* we are measuring in neuroimaging is crucial. Analyzing the nature of the measures for the considered samples is essential. In this respect, psychometrics is (and should be) of great help for refining neuroimaging research.

5. Voxel-based lesion symptom mapping (VBLSM)

Recent lesion studies support the usefulness of refined psychometric approaches for the study of the brain bases of intelligent performance. For instance, Gläscher et al. (2010) studied a large sample of patients with single, focal, stable, and chronic lesions in the brain. The main question was: how does the location of brain damage preclude proper intellectual performance as assessed by the Wechsler's battery? In support of the restricted version of the P-FIT model (meaning the special role of parietal and frontal regions of the brain), only damage in (left) parietal–frontal regions (and their connections) was correlated to performance sores. However, when only the *g* score was analyzed (computed with hierarchical factor analysis), a region in the left frontal pole was found to be unique to *g* (not captured by any intelligence measure). The authors concluded that the distributed processing required by intelligence performance is consistent with the control mechanism found in Brodmann area 10 for *g*.

Using a similar approach, Barbey et al. (2012) analyzed over one hundred and eighty patients. Intelligence and executive function measures were administered and VBLSM was computed. In agreement with the findings reported by Gläscher et al., results revealed that worse performance was related to damage within a network distributed in (left) parietal–frontal regions. The authors supported the view that *integration* is key for understanding the strong relationship between the *g* factor and executive function. 'Intelligence' and 'ability for integration' are closely related terms, as noted above.

These reports underscore the relevance of parietal–frontal brain regions for investigating individual differences in *g*. But they also show that when the focus is directed towards the specific measures (or to the group abilities tapped by these measures) quite disparate brain correlates are found. This is why the choice of the phenotype to be measured is crucial. All intelligence measures tap *g*, but they are not equally good for doing so, and the simple summation of various test scores (a widespread practice) may be misleading.

6. Intelligence and cognition

So far we have seen that intelligence differences, measured by standardized tests, are related to brain features. Apparently, frontal and parietal lobes are particularly relevant for intelligence, but are these regions the unique brain locations of intelligence? Not really.

We know that, for instance, parietal-frontal regions also support working memory capacity (Wager and Smith, 2003). Therefore, the network defined by these areas of the brain may be relevant for (general) high-level cognition. It is possible to obtain indirect information from previously published reports, but it is better to measure the constructs of interest in the same sample. In this respect, Barbey, Colom, Paul, and Grafman (2013) considered a large