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INTELLIGENCE: AN OVERVIEW

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INTRODUCTION

Studies on the genetics of human cognitive ability provide a powerful tool for understanding human cognition. The goal of this brief introduction to intelligence is to provide an overview of topical intelligence research and theory, in terms that can be integrated with the results and theory of neuropsychology.

A consensus definition of intelligence amongst over 50 researchers in the area was proposed as the "*very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—'catching on,' 'making sense' of things, or 'figuring out' what to do"* (Gottfredson, 1997).

Across all the hundreds of tests and at least dozens of separable abilities studied in neuropsychology, two findings have been especially salient to researchers since the turn of the last century: All these abilities are correlated with each other (Spearman, 1927); and quite astounding double dissociations often accompany acquired or developmental disorders (Rapp, 2002). Both of these approaches (of association and double-dissociation) reflect key conceptual and statistical breakthroughs in psychological modelling (Shallice, 1988) and a goal of this introduction is to render the findings of both into a single framework of genetic neuropsychology.

In this brief introduction to intelligence, I first discuss the relationship between information from associations and information from dissociations. I then summarise a large literature indicating that a general latent ability factor accounts for around half of differences

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in cognition and that this is a highly heritable trait. Finally, I note the biological and genetic findings in intelligence, again with an emphasis on linking the concepts of intelligence to neuropsychology.

Association and Dissociation: A Rapprochement through Structural Modelling

An audience of neuropsychologists needs no reminder that people differ widely in their abilities to create and manipulate mental representations and that these differences are prime data for understanding cognition. The idea that the brain and neuronal integrity are critical to these abilities and that genetic differences impact powerfully on the development of a broad range of mental differences are also fairly universal among neuropsychologists.

Thus far, the goals and interests of neuropsychology and of intelligence researchers appear identical: the use of individual differences in cognition (responding to information, solving, understanding, manipulating, memorising, etc) to understand the structure of the mind and the biological basis of this structure. Where intelligence research differs from the typical approach of neurology and neuropsychology is in its focus on the associations amongst tasks, rather than dissociations and double-dissociations between tasks.

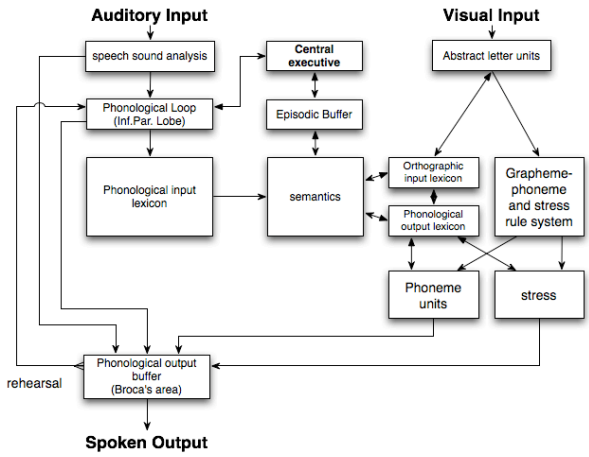


Figure 1. Reading, Language and Working Memory in Cognitive Neuropsychology. On the right hand side are shown components of the dual-route cascaded system for reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Data from patients supports dissociations between the ability to read aloud pseudo-words such as "SLINT" and the ability to read-aloud irregular words such as "YACHT" (A. Castles, Bates, Luciano, Martin, & Coltheart, 2005; Anne Castles & Holmes, 1996). In the center we see semantics and the executive components of working memory (Baddeley, 2007). These are represented as separate modules because dissociations again suggest that there are patients with acquired brain damage who retain the ability to read but no longer access meaning from written language, and other patients who retain meaning despite losing the ability to read. Finally on the left hand side of the model are components of mind implicated in specific language disorder, specifically the systems for speech sound analysis, for brief storage of phonological strings, independent of meaning, and connections supporting rehearsal in short-term memory (Baddeley, 2007).

Represented graphically in Figure 1 and Figure 2, there seems at times a looming gulf between the respective views from neuropsychology (with its box-and-arrow diagrams of painstakingly accumulated from patient studies of dissociations in the mind: See Figure 1) and intelligence research, with its hierarchical tree diagrams built largely from the relationships of performance on tasks in larger group of normally developing individuals (See Figure 2).

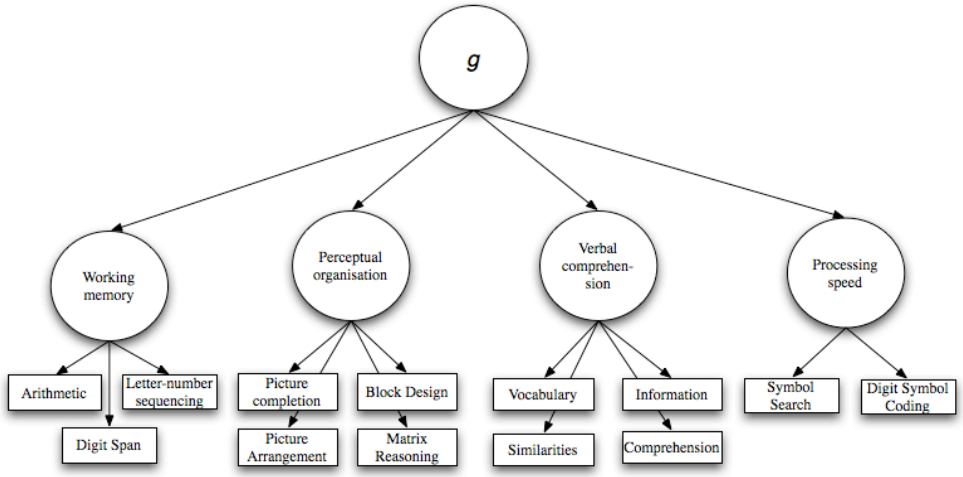


Figure 2. Factor Structure of ability as measured in the Wechsler Adult Intelligence Scale III.

Despite appearances, both of these models are compatible: the same modules would ultimately appear as boxes in both diagrams as the data driving their creation is in both cases the existence of between-task correlations significantly less than one, not explainable by scaling factors such as difficulty.

Where they differ is that the latent variable model of intelligence preserves the raw association data (at the cost of losing the wiring diagram), while the neuropsychological box-and-arrow model preserves connectivity information at the cost of losing information on shared processes.

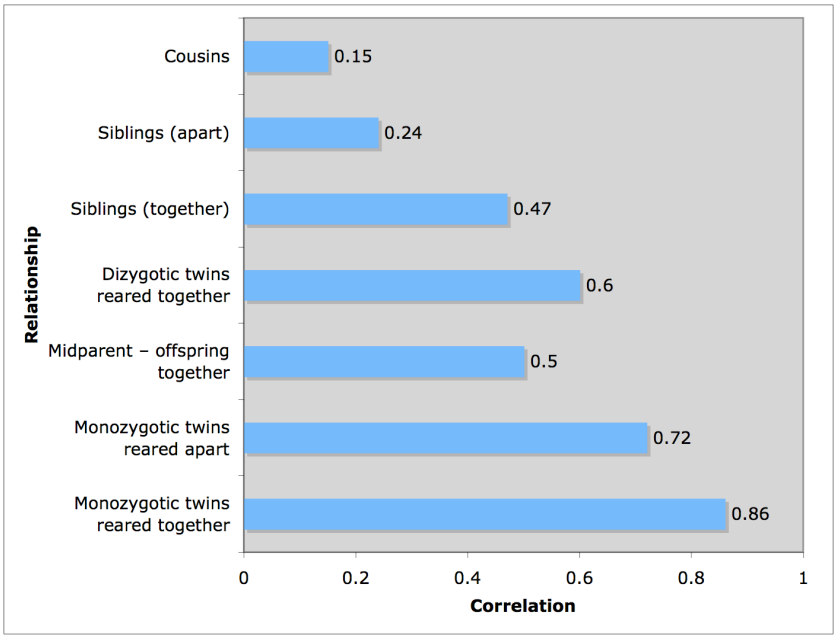
Surprisingly, recent research is revealing that normal variation in tasks reveals the same structure double dissociations patient data contribute critical data on the separability of dissociations modelled as boxes fact that the abilities do not correlate 1.0

Figure 2 shows a representative finding of the structure of intelligence research from the WAIS (Wechsler, 1997), a test common to both neuropsychology and intelligence research. It can be seen that the 13 WAIS sub-tests correlate 0.49 (range .26 to .77). Since the first formal mental test was devised (Binet, 1905/1916), structures closely related to that shown in Figure 2 emerge from all of the many hundreds of test batteries devised and administered to many millions of test-takers (Ian J. Deary, 2001).

The genetic and environmental influences on mental abilities have now been examined in a diverse range of genetically informative studies totally over 200,000 monozygotic (MZ) and dizygotic (DZ) twin-pairs (Summarized in Table 1). Two key findings from this research are

that ability is highly heritable and that genetic influences increase rather than decrease over time, while the influence of within-family effects decreases over time, so that by adulthood and into old age, 70-80% of the differences observed in test performance in adulthood and old age are genetic (See Figure 3). Crucially for neuropsychological research, genetic studies of normal adolescents and adults indicate clearly that this correlation is almost *entirely* genetic in origin (Plomin & Spinath, 2004).

Table 1. Summary of world literature on familial effects on IQ (adapted from Bouchard & McGue, 1981)



The Biology of g

While general ability emerges very reliably as a heritable trait, it is only more recently that researchers have begun to uncover biological bases for general intelligence. Perhaps surprisingly, the key finding of the last 20 years of research has been the finding that the strongest physical brain correlate of intelligence is brain volume itself, with a meta-analysis of several thousand samples cases suggesting that brain volume difference explain 10% of IQ variance, with regional difference contributing further variance (McDaniel, 2005). Twin studies indicate both that brain volume is highly heritable (Thompson et al., 2001; Pennington et al., 2000) and that general ability and brain volume share a genetic correlation (Posthuma et al., 2003). This suggests that researchers on genetic syndromes should examine regional and global changes in brain volume as potential biological indicators (Gray & Thompson, 2004).

In addition to the global volume of the brain, recent studies have highlighted the importance of regional variation in brain activity and volume in intelligence (Jung & Haier, 2007). This further supports the role of genetic analyses of brain volume variation as a tool to identify brain systems with shared genetic influences but diverse anatomical boundaries (Toga & Thompson, 2005). Case studies of genetic abnormalities can play a potential crucial role in this field.

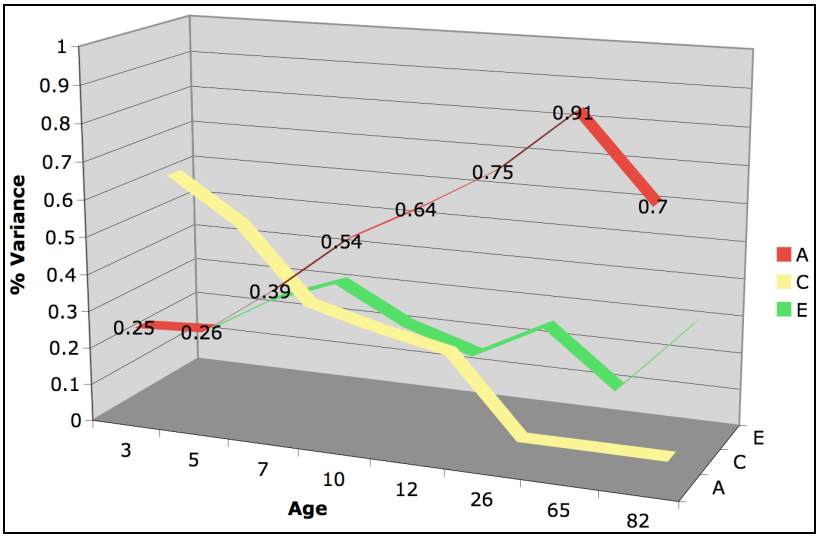


Figure 3. Genetic and Environmental Components of Intelligence from age 3 to age 82. A (red) is the observed heritability, C (yellow) is the effect of shared or family environment factors such as SES and home, and E (green) is the remaining effects, which are unique to each individual and include measurement error. The Figure shows that at very young ages family environment has a large effect on cognitive ability, but that by young adulthood, this has been replaced with large effects of genes, which continue to rise in relative importance into old age, possibly declining again as people reach their 80s. The data are combined results from (Bartels, Rietveld, Van Baal, & Boomsma, 2002; McClearn et al., 1997; Danielle Posthuma, de Geus, & Boomsma, 2001; Reynolds et al., 2005; Spinath & Plomin, 2003).

Molecular Genetics

While the heritability of intelligence implies the existence of genetic effects on ability, the limited research on intelligence to date has been less productive thn has similar research on more specific traits such as dyslexia and even normal variation in reading, where as many as 11 regions containing reading-related genes have been identified (Bates et al., 2007). By contrast, studies of general intelligence suggest that specific genes such as *klotho* (Ian J Deary et al., 2005) and *COMT* (catechol-O-methyl transferase) (Winterer & Goldman, 2003 134-163) have small effects, consistent with a polygenic view of the heritability of intelligence, i.e., a view in which the genes affecting intelligence number in the hundreds, with none having a large effect on population variation. This view that genes for intelligence will have

small effects is further buttressed by the first genome-wide linkage studies for intelligence, which suggested that the genetic effects are widely distributed with none explaining more than 2-3% of the variance in IQ (Luciano et al., 2006), and by exploratory association studies, which suggest that a reasonable estimate for the average gene effect size might be on the order of .1% of the population variance (Butcher *et al.*, 2005). These conclusions remain tentative, as all the studies to date have been modest in size, and genome coverage, and, importantly, have lacked the ability to detect genetic effects mediated by multiple uncommon mutations, as well as being unable to detect copy-number variations, both of which seem likely to harbour significant cognitive effects (Sebat et al., 2007).

These results do, however, suggest that the results of studies of the neuropsychological effects of chromosomal abnormalities, as reported in the rest of this volume will prove to be a critical source of candidate genes for understanding general cognition (for instance the case of microcephaly related genes such as *ASPM* (Cox, Jackson, Bond, & Woods, 2006). The pace of this research suggests the likelihood that the next five years will see notable progress in both intelligence and neuropsychological genetics of specific and general genes through collaboration and replication of effects detected using the *g* approach, and those discovered through family-based syndromic studies.

In conclusion, it is hoped that this introduction has made the approach of intelligence researchers more accessible to those in neuropsychology, and highlighted progress in this field using phenotypes such as brain volumes and the methods of association and linkage as well as the difficulties encountered in the search for genes affecting diverse cognitive and biological functions.

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