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Research paper

Separate contributions of general intelligence and right prefrontal neurocognitive functions to academic achievement at university level

Graham Pluck*, Carlos B. Ruales-Chieruzzi, Edgar J. Paucar-Guerra, M. Victoria Andrade-Guimaraes, Ana F. Trueba

Quito Brain and Behavior Laboratory, Universidad San Francisco de Quito, Quito, Ecuador

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ABSTRACT

It is hypothesized that performance on frontal-lobe neuropsychological tests and intelligence tests may independently contribute to variation in academic achievement in higher education. We examined the ability of an IQ test (the WAIS-IV) to predict grade point averages (GPA) in a sample of 64 undergraduate students. We also included a battery of five neuropsychological assessments of frontal-lobe functions, all known to be unrelated to general intelligence and linked to right-prefrontal function. Regression analysis with stepwise entry of variables revealed separate contributions to the variation in GPA scores explained by general intelligence and two different measures of response inhibition (Stop-signal and Hayling). The addition of the inhibition measures more than doubled the amount of variance in GPA explained by general intelligence alone, from adjusted R^2=.115 to adjusted R^2=.239, suggesting an important role of right prefrontal-mediated response inhibition in high-level academic achievement. This contrasts with the mainly left-hemisphere contribution from general intelligence.

1. . Introduction

There has long been an interest in predicting academic achievement through cognitive testing. This is one of the primary reasons that intelligence tests were first developed [1,2]. Indeed, intelligence testing can predict academic performance very well in some contexts. A study of 70,000 British school children found that a psychometrically derived measure of general intelligence correlated very highly (r=.81) with a measure of school leaving qualifications [3].

However, other studies have shown much less impressive associations, particularly when adult learners are considered, such as in higher education contexts. For example a study in India found no relationship between intelligence tests scores and academic achievement in a sample of 120 postgraduate students [4]. Similarly a study of 93 undergraduate students in London, the UK, found very low and not statistically significant correlations between academic performance (as measured by end of year exam grades) and IQ [5]. In fact, a recent meta-analysis found a mean observed effect size (r^+) between intelligence test performance and academic achievement at university level of only about .2 [6] which therefore only accounts for a tiny proportion of the variance.

There may be many reasons why IQ is only weakly predictive of university level performance. For example, students are often selected based on their performance in challenging entrance examinations. Consequently this limits the range of intellectual ability observed in student samples [5]. Furthermore, non-intellective factors such as effort regulation and self-efficacy have been found to be important predictors of university level grades [6]. Another reason may be that IQ tests are not specifically designed based on neuroscientific principles and are in fact failing to focus on how cognition drives adaptive goal-directed behavior. In fact, the rationale behind intelligence test development is psychometric, to develop tests that measure well. One feature of this psychometric approach has been the focus of assessments that measure the same basic underlying concept – *general intelligence*. This has been motivated by the observation that scores on cognitive tests correlate positively with each other, suggesting they are measuring some fundamental neural property [7]. Indeed, the development of intelligence tests has been driven by the need to best measure this general intelligence, or the *g-factor*.

Although, there is certainly something of great interest to

* Correspondence to: College of Social Sciences and Humanities, Universidad San Francisco de Quito, Diego de Robles y Vía Interoceánica, Cumbayá, Ecuador.
E-mail addresses: gpluck@usfq.edu.ec (G. Pluck), bruales@gmail.com (C.B. Ruales-Chieruzzi), edgarjpaucarg@gmail.com (E.J. Paucar-Guerra), victoria.andradeg@gmail.com (M.V. Andrade-Guimaraes), atrueba@usfq.edu.ec (A.F. Trueba).

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cognitive- and neuroscientists in the concept of *g*, as it is also known, there is no direct theoretical link to adaptive goal-directed behavior. The concept of *g* is statistically related to abstract problem solving in a range of tasks, but not obviously to behavior regulation mechanisms. On the other hand, neuropsychologists have developed approaches to measure and explain where goal-directed behavior fails, or at least fails to lead to the most adaptive outcome for the individual. In particular, studies of frontal lobe and basal ganglia damaged patients have revealed a range of behavioral dysregulations such as the apathetic, disinhibited and dysexecutive syndromes, linked to damage to the medial, orbitofrontal and dorsolateral prefrontal cortices respectively [8]. These neurobehavioral syndromes appear to show the breakdown of effective goal-directed behavior [9]. Furthermore, neuropsychologists have developed a range of assessments to measure impairments associated with damage to the prefrontal-subcortical circuits. Such tests cover a wide-range of abilities, but the majority tend to measure 'executive functions' such as response inhibition, task shifting and planning.

From a neuropsychological perspective, such tests may also be useful in the measurement of effective goal-directed behavior in non-clinical contexts. Indeed, a recent study of self-report executive functions in a large sample of students starting university found that better executive functions predicted better attainment at the end of their first year [10]. Furthermore, it has been shown that clinical executive function tests linked to the efficiency of the prefrontal cortices are at least as good as traditional tests of intelligence in the prediction of academic achievement of university students [11]. These better executive skills may allow students to generally prosper in university environments, rather than resolve specific cognitive problems. Support for this comes from a study in which it was shown that those university students with the best working memory scores more readily developed information literacy skills [12].

Furthermore, there is a wealth of evidence linking executive functions to educational achievement in children. For example, measurements of executive functions including working memory in pre-school age children have been shown to predict later school performance. In particular, visuospatial short-term memory skills (measured at age 4) predict better math, and general executive function scores predict better attainment in general at age 7 [13]. A separate study of 11-year-old children observed another prefrontally-mediated executive function, inhibition, was predictive of general school attainment and also confirmed that working memory scores predict math scores. Furthermore, these two broad executive functions (working memory and inhibition) appear to make independent contributions to attainment, although the magnitude of the relationship appears to be much greater for working memory [14]. Indeed, in children, working memory ability is superior to general intelligence in prediction of academic achievement in general [15].

Therefore a focus on frontal lobe functions, and assessments developed to measure those functions, may ultimately be a more productive approach in understanding complex behavior than the concept of general intelligence. However, it has become clear that many but not all executive function tests are highly correlated with general intelligence and in fact may be measuring the *g*-factor rather than any specific, modular, cognitive ability [16]. A recent modeling study for example found that in a combined clinical and non-clinical sample, general intelligence including crystallized but particularly fluid intelligence, was highly correlated with several supposed executive functions, most strikingly with working memory [17]. Furthermore, frontal lobe lesions tend to lead to very large impairments in general intelligence, suggesting that frontal lobe function may in fact be the biological basis of the *g*-factor [18].

Nevertheless, there appear to be some frontal-lobe neuropsychological functions which are not, or only weakly, related to the *g*-factor. One study by Roca et al. [19] compared the performance of a group of frontal lobe damaged patients with a healthy control sample on a range of common neuropsychological tests of frontal lobe function. They also used a test of 'fluid intelligence', thought to be a strong measure of general intelligence. As expected, the frontal lobe patients performed significantly below the levels of the controls on all assessments. The researchers then examined the between-group differences while covarying the effects of reduced general intelligence. This revealed that frontal damage related impairments on most of the supposed executive function tests could be fully accounted for by reduced general intelligence. However, this analysis also revealed five tests where performance was impaired by frontal lobe damage, but the impairments could not be explained by general intelligence reductions [19]. These five tests, the Hotel Task [20], Proverbs [21], Faux Pas Test [22], Go/No-go [23] and the Hayling Response Suppression Test [24] therefore appear to be non-*g* related measures of frontal lobe function. Despite being conceptually linked by their independence from *g*, they appear to measure a diverse range of abilities including multi-tasking (Hotel Task), abstract reasoning (Proverb Test), theory of mind (Faux Pas), psychomotor response inhibition (Go/No-go/Stop-signal) and verbal response suppression (Hayling). They are therefore ideal candidate tests for understanding goal-directed behavior functions of the frontal lobes in contrast to the concept of *g* or general intelligence.

Interestingly, a lesion analysis linked impairments on these five different non-*g* neuropsychological tests to damage of the right prefrontal region, specifically the right frontal pole (BA10) [19,25]. This contrasts sharply with lesion studies that have demonstrated that tasks that are known to load highly on *g* are specifically linked to left-hemisphere damage of the parietal and frontal cortices and white matter tracts linking them [26,27]. This therefore suggests that general intelligence and the five neuropsychological tests described are not only functionally independent, but may have separate neurological bases. They consequently may make independent contributions to the high-level goal directed behavior such as needed for success in higher education.

In the current research we attempted to explore the relative contributions of general intelligence and the five non-*g* frontal lobe tests identified by Roca et al. [19] to academic achievement at university level. In addition we included a measure of working memory capacity, considering that this is closely linked to general intelligence and may, in some cases, be a better predictor of academic achievement than IQ. It was hypothesized that non-*g* related neuropsychological functions and traditional general intelligence/working memory may both be independently contributing to achievement as measured by grade-point average data (GPA).

2. Methods

2.1. Design and analysis

The aim of this research was to examine the ability of general intelligence and specific tests of frontal lobe function to predict GPA scores of undergraduate students. Thus a single sample of 64 students was recruited and all were individually assessed with a range of neuropsychological tests as well as with a standard IQ assessment known to load highly on the construct of psychometric *g*. Data on these assessments were then compared via correlations and regression analysis to examine the relative contributions to variance in GPA. For reporting descriptive statistics, numbers less than 10 are given to 2 decimal places, numbers over 100 to