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Differential associations of neurobehavioral traits and cognitive ability to academic achievement in higher education

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Abstract

Background: People vary between each other on several neurobehavioral traits, which may have implications for understanding academic achievement.

Methods: University-level Psychology or Engineering students were assessed for neurobehavioral traits, intelligence, and current psychological distress. Scores were compared with their grade point average (GPA) data.

Results: Factors associated with higher GPA differed markedly between groups. For Engineers, intelligence, but not neurobehavioral traits or psychological distress, was a strong correlate of grades. For Psychologists, grades were not correlated with intelligence but they were with the neurobehavioral traits of executive dysfunction, disinhibition, apathy, and positive schizotypy. However, only the latter two were associated independently of psychological distress. Additionally, higher mixed-handedness was associated with higher GPA in the combined sample.

Conclusions: Neurological factors (i.e., neurobehavioral traits and intelligence), are differentially associated with university-level grades, depending on the major studied. However, mixed-handedness may prove to be a better general predictor of academic performance across disciplines.

Keywords: Academic attainment; personality; frontal-subcortical circuits; schizotypy; handedness; higher education

There has long been a tendency within psychology and behavioral sciences to assume that all people have more or less the same psychological and neurological processes. This assumption allows groups to be compared in experimental and neuroimaging studies. However, it is becoming clear that that there is a large amount of variation within the 'normal' population concerning neurocognitive processes and neurobehavioral traits and that averaging groups may miss important neurocognitive differences at the subject level [1, 2]. This has implications for understanding education, particular the neuroscience of education [1, 3].

One notable example of the diversity within psychological phenomenon is synesthesia, in which some individuals report perceptual experiences which appear to cross modalities, such as hearing colors. This appears to be present in about 4.4% of the adult 'normal' population [4]. In contrast, there are people who seem to have no visual imagery at all, known as congenital aphantasia, affecting an estimated 2 to 5% of the 'normal' population [5]. Interestingly, there are some indications that these extreme variations in the normal phenomena of perceptual experience may be linked to academic endeavor, synesthesia appears to be more common in arts students than the general population [6], and there are anecdotal reports of aphantasia being particularly common among scientists [7]. These two examples indicate that the variation in cognitive processes among people may be an important factor in understanding academic achievement.

Inter-individual variation in processing is also seen at the neuronal level. As an example, functional MRI has shown that adult skilled readers appear to prefer one of two different routes to read aloud irregularly spelled words [3, 8]. Some use a system based on the left occipitotemporal regions but invoking the left putamen and prefrontal cortex. Others tend to use a more posterior system, invoking the intraparietal sulcal regions bilaterally to pronounce words [8]. This phenomenon of the same behavior resulting from different neurological processes is referred to in biology as degeneracy [1]. Furthermore, this degeneracy underling word pronunciation has educational implications as people favoring the posterior system showed the same imbalance of reading ability between irregular and non-word pronunciation seen in phonological dyslexia, and those favoring the anterior system the same imbalance as see in surface dyslexia [8]. The anterior pattern, i.e. more difficulty with irregular word production, is a relatively strong predictor of academic achievement [9].

The above described concepts, being 'normal' variation in the manifestation of neurocognitive processes, are broadly consistent with the concept of neurodiversity. This movement, which began among communities of autistic individuals, views conditions such as autism as being part of normal human variation, not a pathology [10]. An analogy is sometimes made to being either right- or left-handed, both are neurologically determined variations of human behavior, but neither is a disorder [11]. Indeed, there is significant merit to this approach, as traits linked to autism do seem to be distributed in the general population, with diagnosis of autistic spectrum disorder being based on severity rather than any discrete categorization [12]. The concept of neurodiversity is often extended to other disorders such as, attention deficit/hyperactivity disorder (ADHD) and even bipolar disorder. In support of the neurodiversity approach, the expression of supposedly pathological traits may be disadvantageous or advantageous, depending on the context. As examples, autistic traits are raised in mathematicians and scientists [13], and traits linked to bipolar disorder are raised in professional comedians [14]. Although the concept of neurodiversity (as opposed to medical disorder) is reasonably well accepted for several contexts, including autism, few people object to the identification of acute psychiatric states as being medical disorders, because they cause functional impairment in any environment [11].

It seems reasonable that some of this variation in neurobehavioral traits may influence academic achievement, particularly within higher education, in which demands for efficient cognitive processing, or perhaps creativity, are high. Related to this, performance on neuropsychological tests, which also show significant variation even within the 'normal' population [15], are known to predict academic achievement. This has been particularly productive in regards to working memory in younger learners [16, 17], but less successful within higher education, where long-term memory and behavioral regulation processes may be of more importance [18-20]. It is notable that associations with neuropsychological variables are seemingly always in the direction of lower test performance with lower academic achievement.

If normal diversity in neurobehavioral traits is similarly linked to academic achievement, in general it would be hypothesized that high traits would be linked to poorer achievement. This does not contradict the neurodiversity approach, as an example, traits linked to schizophrenia risk are distributed within the normal population [21], but do predispose individuals to functional impairment in the frank disorder and the associated cognitive impairment. Furthermore, schizophrenia and related disorders fall into the category of states which reduce the individual's functioning in all environments. In contrast some traits can be adaptive in certain circumstances, such as the case of autism-related traits and scientists. Others, such as handedness, or at least the underlying neurological differences that produce the handedness phenotypes, are also potentially advantageous or disadvantageous depending on the context.

Associations between neurobehavioral traits, if observed, may also provide some insight into the question of why intelligence appears to be such a poor predictor of academic achievement at university level study. Some studies have reported that there was no significant association between grades and intelligence test scores [22, 23], while a meta-analysis reported a mean correlation between intelligence test scores and GPA of only 0.2 [24]. Neurobehavioral traits may prove to be better predictors than intelligence in higher education due its complexity and requirement of behavioral self-management. Although given that the context and the adaptive function of neurobehavioral traits are closely linked, even if a trait is linked to performance in one academic context, it may not be linked in another.

In the current research we investigated the associations between several neurobehavioral traits and academic performance in two different groups of university students, chosen to be exemplars of social science study and technical study: Psychology undergraduates and Engineering undergraduates. The research was essentially exploratory, investigating several different traits, including those associated with frontal-subcortical impairment, ADHD, autism, handedness and schizotypy. We also included a measure of intelligence and a measure of transient mental distress as these can also be correlates of academic performance and could obscure the relationships between academic performance and neurobehavioral traits. These assessments are described in detail below. The results of the main study are reported in Study 2. However, as the assessment tools employed are particularly oriented to clinical assessment, we first investigated their psychometric properties, refining the scales as necessary to increase their reliability in the current context. The results of these psychometric appraisals and refinements are reported in Study 1.

Study 1: Psychometric properties of the assessment tools

Aims and design

The aim of this part of the research was to establish the psychometric properties of the various scales. This is so that their associations with academic achievement can be investigated in Study 2. A varied sample of participants was recruited and completed all of the questionnaires of interest. A sub-sample returned on a second date, in order that we could assess the 4-week test-retest reliability. In addition, for the whole sample we wished to assess the unidimensionality of the various scales, the simplest way to do this is to examine the inter-correlations of the different items within each scale. Unidimensionality can be assumed if there is a mean inter-item correlation of between 0.15 and 0.50, and that almost all of the inter-item correlations fall within the same range [25, 26]. This inter-item correlation approach is a better measure of test reliability than Cronbach's alpha which does not necessarily indicate unidimensionality, and is partly a function of the number of items in a scale [25-27]. Nevertheless, we also calculated and report the Cronbach's alpha values as this is the more recognized estimate of internal consistency.

Participants

Sixty-six individuals were recruited from several sources to provide a sample in which there would be sufficient variation in responses to check for internal consistency and unidimensionality of the various scales. These comprised of three different groups. One group contained 19 individuals recently hired to work in a governmental ministry in the city of Quito, Ecuador, and recruited as part of an occupational psychology project. The age of the participants was not recorded but they were generally young adults aged between 20 and 30. Ten were male. Another group were 26 undergraduate students at a private university in Quito (M_{age} = 21.55, range 18-27; 7 male). The final group were 21 students or employees at the same University but were recruited into a Test-Retest arm of the research (detailed below). This Test-Retest sample comprised of nine students, six cleaners, four professors, one research assistant, and one person who self-described as being a housewife (M_{age} = 28.55, range 18-48; 8 male).

Materials

Adult ADHD Self-Report Scale-V1.1 Screener (ASRS-Screener)

ADHD is a well-recognized neurodevelopment disorder characterized by either or both of attentional problems and hyperactivity. It is associated with executive function impairments [28] and poor workplace [29] and academic performance [30]. The ASRS-Screener is a brief six-item screening test for the presence of ADHD. The six items are those that have been found to be the most sensitive to detection of ADHD [31] from the 18 criteria for ADHD listed in the larger scale and which form the basis of a DSM-IV-TR diagnosis of ADHD [32]. Each of the six items has five possible responses ranging from 'never' to 'very often'. Despite the five-point range for each item, the ASRS-Screener is usually used clinically with dichotomous scoring (0 or 1 point) for each item. However, the continuous Likert scoring (0 - 4 points) is preferred in research and in fact has better reliability and validity than the dichotomous scoring method [33]. Therefore, continuous scoring was used in this report. The ASRS-Screener is published by the World Health Organization in several languages. We used the Spanish version. As ADHD symptomology is consistently linked to poor functional outcomes, high scores may be linked to poorer academic performance.

Frontal Systems Behavior Scale (FrSBe)

This questionnaire measures three different neurobehavioral profiles or personality traits that are directly derived from neurology and neuroscience [34-37]. The three scales are Apathy, Disinhibition, and Executive dysfunction, and match onto the regional syndromes (with the same names) seen after damage to the prefrontal cortex [38]. Anatomically, the three different syndromes/traits are linked to the frontal-subcortical circuits described in a now classical paper by Alexander, DeLong, & Strick in 1986 [39]. These are: i) The dorsolateral prefrontal circuit that projects to the dorsolateral head of the caudate nucleus, which then projects to the dorsomedial globus pallidus and then to the thalamus before closing the circuit by projecting back to the dorsolateral prefrontal cortex. ii) The lateral orbitofrontal circuit which projects to the ventromedial caudate nucleus, and then to a more medial part of the dorsomedial globus pallidus, and then to the thalamus closing the circuit with projections back to the lateral orbitofrontal cortex. iii) The anterior cingulate circuit projects to the ventral striatum, the rostrolateral pallidum and then to the thalamus before projecting back to the anterior cingulate cortex. Although identified over 30 years ago, these three neurobehavioral circuits (and two others not relevant here- the motor circuit and the oculomotor circuit), are well-established and important features of brain organization and continue to provide significant insights into human behavior in health and disease [40-46].

The three frontal-subcortical circuits have been proposed to be fundamental bases of normal human behavior, with the dorsolateral prefrontal circuit involved with executive functions, the lateral orbitofrontal circuit involved with social behavior and self-control and the anterior circuit with motivation [40, 41, 46, 47]. The FrSBe is an attempt to measure, in a questionnaire, neurological dysfunction of these three circuits underlying normal human goal-directed behavior [34, 35, 48]. Functioning of the three circuits is measured on three subscales of the FrSBe, named after the three prefrontal syndromes (Apathy, Disinhibition, and Executive dysfunction). Although usually used to measure neurological syndromes, as the circuits are thought to be the biological basis of goal-directed behavior in health, the FrSBe has frequently been applied to non-clinical samples [42, 49, 50].

We used the Spanish language version of the FrSBe under special license from the publisher: Psychological Assessment Resources. This is an official translation of the original English language version and has the same number of items (Disinhibition- 15 items, Apathy- 14 items, Executive dysfunction- 17 items). All items are scored on a five-point scale ranging from 'almost never' to 'almost always', with higher scores indicating greater dysfunction. The English language version has been validated as being particularly sensitive to frontal lobe impairment [35, 37], as has the Spanish-language version used here [51]. As high scores indicate neurological dysfunction, we expected that they may be associated with poorer academic performance.

Schizotypy Personality Questionnaire – Brief (SPQ-B)

It has long been recognized that schizotypal personality disorder shares symptomology with, and is a risk factor for, the development of schizophrenia [52]. Furthermore, the same features that overlap (e.g. magical ideation, perceptual aberrations, anhedonia) also occur on a continuum within the non-clinical population, and also act as a risk factor for the development of schizophrenia [21]. This 'normal' variation is called schizotypy and ranges from minimal impairment through personality disorder to psychosis. The SPQ–B is a 22-item questionnaire, originally used to identify personality disorder [53] but has since been used as a psychometric measure of schizotypy [54]. High schizotypy measured with the SPQ-B within non-clinical samples is associated with many of the same neuropsychological problems as schizophrenia, e.g. response inhibition and interference control impairments [55]. Although schizotypy appears to exist on a continuum within the normal population, it is not considered to be a 'healthy trait' due the risk for later conversion to personality disorder or psychosis [56].

Although the original SPQ-B was scored on a binary (true/false) basis for each item, it has been shown to have good psychometric properties when scored on a five-point Likert scale for each item, including for the Spanish language version used here [57]. We used this Likert scoring. In addition, multiple factor-analytic studies have shown that the SPQ-B has a three-factor structure, and thus three subscales of schizotypy are identified [53, 54, 57]. These are positive features, known as the Cognitive-perceptual subscale, negative features, known as the Interpersonal subscale and a third subscale named Disorganization which contains items probing unconventional or eccentric behavior. Higher scores on these scales indicate greater risk of pathology and we could expect them to be associated with greater difficulty in higher education. Interestingly, the factors correspond well to the observed tripartite division of symptoms in schizophrenia into positive, negative and disorganized [58]. Total scores as well as subscale scores were investigated in the current research.

Barratt Impulsiveness Scale-15 (BIS-15)

Impulsiveness is a normal personality variant characterized by a tendency to act prematurely and without foresight and is thought to indicate efficiency of cognitive control mediated by the frontal-subcortical circuits [59]. Nevertheless, despite being a normal trait, it may also be a behavioral endophenotype (meaning a stable, hereditary psychological trait that can be used to identify a disease state) of several pathological states, including ADHD, drug dependence and eating disorders [60]. Impulsivity is also associated with negative social outcomes: high impulsivity is observed in prisoners [61] and associated with alcohol abuse by students [62], as well as poor academic performance [19, 62]. Although there are several measures of impulsivity, trait impulsivity is most often measured by the Barratt Impulsiveness Scale-11, a 30-item self-report scale [61]. This contains three subscales identified through factor analysis and named Attentional, Motor, and Non-planning impulsiveness. More recently a 15 item version has been produced which has the same three subscale structure (5 items for each subscale), known as the BIS-15 [63]. We used a validated Spanish-language version of the BIS-I5 [64]. It is expected that high-scores would be associated with poorer academic performance.

Autism-Spectrum Quotient-10 (AQ-10)

Autism-spectrum disorder, associated with early onset social communication impairments and repetitive behavior, has a prevalence of about 0.1 to 0.5 % and a probable genetic basis [65]. However, traits that define the clinical disorder appear to vary continuously within the general population with the distinction between affected and not-affected being somewhat arbitrary [12]. This is one of the reasons that multiple diagnostic classifications are no longer made based on severity of disorders (i.e. autistic disorder, high-functioning autism or Asperger's syndrome) in the DSM-V [66], autistic behavior is now considered on a spectrum of severity. Consequently, autistic traits can be measured on a continuous scale, one of the most common scales being the Autism-spectrum Quotient (AQ scale) [13].

The AQ scale is a self-report questionnaire comprised of 50 items, measuring five different traits associated with the autism spectrum: 'social skill', 'attention switching', 'attention to detail', 'communication', and 'imagination'. For identifying cases, a binary scoring method is usually used (despite the four-choice responses for each item), however, in university student populations the Likert scoring method is preferred as it has better psychometric properties [67]. Interestingly, despite social-communication impairments and a high-rate of mental retardation among diagnosed cases of autism-spectrum disorder [65], high scores on the AQ scale are also associated with high achievements in some subjects, such as mathematics [13], and also with supranormal performance on some visuospatial parts of cognitive tests, such as Block Design [68] and Raven's Advanced Progressive Matrices [69], both of which are used as measures of intelligence. We employed a validated short-form of the AQ scale, which contains two items from each of the five subscales giving a total scale length of 10 items, hence its name, the AQ-10 [70]. Likert scoring was used. Given the associations between high scores with clinical disorder, but also with supranormal performance in some areas, they could be associated with either better or poorer academic achievement.

State-Trait Anxiety Inventory (STAI)

Anxious states can be a normal response to stressful situations. On the other hand, some people may tend to be anxious regardless of the situation, their anxiety being a stable trait. It is the latter trait manifestation which is of particular interest here. We used the trait-anxiety section of the STAI [71]. This is a 20 item self-report scale rated on a Likert scale. State anxiety is associated with increased risk of the development of major depression, and this risk is probably caused by neurocognitive processing biases, particularly involving threat

[72]. These effects may be mediated by reductions in dopamine transmission in people with high trait anxiety, particularly involving the amygdala and anterior cingulate cortex [73]. It is of relevance here because, other than being an endotype of major depression, trait anxiety is also associated with poor academic performance, which may be mediated by effects on working memory ability [74].

Edinburgh Handedness Inventory (EHI)

One of the most basic neurologically-mediated individual differences is handedness. Although the majority of people prefer to use their right hand for most tasks, a minority prefer the left and some show little to no preference (mixed-handedness). We measured handedness with the EHI, a ten-item scale that is used to produce a handedness coefficient, ranging from completely left handed (-100) to completely right-handed (+100) [75]. That hand preference is reflected in brain organization is most clearly seen in respect to hemispheric lateralization on language processing. For most people there is clear bias for the left hemisphere to process language, but in highly left-handed people (EHI coefficient of -100) about 27% are right-hemisphere dominant. This shift to the right hemisphere only occurs in about 4% of highly right-handed people (EHI coefficient of +100) [76].

The neurocognitive implications of hand preference are not well understood. It is known for example that either strong right- or left-handedness is associated with poorer episodic memory test performance, compared to people with mixed-handedness [77]. On the other hand, adolescents with high mixed-handedness (i.e. ambidextrous) tend to show worse academic performance than those with lateralized preferences [78]. Also, non-right-handedness is more common in people with learning disabilities [79]. But in contrast, left-handedness may be associated with more efficient inter-hemispheric communication [80].

Given these differences, either left- or right-handedness, or perhaps greater or lower mixed-handedness could be linked to academic achievement. Both of these issues are explored in the current research, based on responses to the EHI.

General Health Questionnaire-28 (GHQ-28)

As the above listed measures all are assumed to measure stable neurobehavioral traits, it is important to also consider more transient emotional states. This is because affective disorder is itself associated with poor academic performance, probably through its negative impact on executive functioning [74]. Furthermore, trait measures such as the those listed above are not necessarily stable in terms of measurement, in the presence of emotional state variation. It has been shown that self-reporting of emotional traits is partly dependent on transient variation in emotional states [81]. In the current research we included the Spanish version [82] of the General Health Questioanire-28 (GHQ-28) [83]. This is one of the most widely used scales of emotional distress. It contains four different subscales, each comprised of seven items, measuring A) Somatic symptoms, B) Anxiety/Insomnia, C) Social dysfunction and D) Depression. It is very much a current status examination, as each item asks whether there has recently been a change in the particular symptom. This was included in the current research primarily to provide a control variable. As it is expected that high emotional distress scores will be associated with poor academic achievement, we wished to examine how they may mediate scores between neurobehavioral traits and grades.

Procedure

All participants provided written informed consent in accordance with the local ethics committee approved protocols. All participants completed the eight questionnaires detailed above. For the ministry employees this was a group administration at their place of work. The remainder completed the questionnaires in one-to-one sessions in a psychology research laboratory at the University. A sub-sample of 21 participants returned to the laboratory after a mean of 29 days (range = 21-41) and completed the same set of questionnaires a second time, in order to estimate the test-retest reliability. However, the EHI measure of hand preference was misadministered in the test-retest arm of the research (as an interview scale rather than as a self-report). Consequently, that data has been excluded, but unidimensionality and internal consistency have still been calculated on the 45 participants who performed the scale as a self-report measure. For those analyses the 1-5 point scoring system per item [84] was employed as that gives an equivalent measure of the handedness coefficient, but as it is per item, can be used to calculate internal consistency etc.. The other questionnaires were administered correctly.

Results and discussion of Study 1

For each scale or subscale, the matrix of Spearman correlations was examined. Generally, it was found that items within scales inter-correlated at acceptable levels. However, items which had low or negative correlations with other items within the same scale were removed. For example, in the Cognitive-perceptual subscale of the SPQ-B there are eight items, however, two of the items (items 9 and 17) had poor correlations with the other six items and so were removed. The remaining six items had a mean inter-item correlation of 0.358 (range 0.202 – 0.589). The Cronbach's α of this reduced sub-scale was 0.778, and the test-retest reliability correlation was $r = .711$. This suggests that our six-item version of the Cognitive-perceptual subscale has adequate internal consistency, unidimensionality and temporal stability. The details for the other scales and subscales are shown in Table 1.

Although this resulted in shortening of many of the scales, this is preferable to including items which are not correlated with the other items. It also allows us to 'strengthen' the scales by removing items that appear not to measure the same latent construct as the other items within the scale. The strengthening makes the scales more reliable in the socio-geographic context in which we intend to apply them, and potentially improves our statistical power to detect associations. This psychometric pruning of items was also necessary because some of the scales are directed at clinical populations, and their reliability in non-clinical samples cannot be assumed. This is particularly true for the FrSBe which is designed for use in neurological patients. That is probably the reason why several items had to be removed on its subscales of Apathy, Disinhibition and Executive dysfunction. Nevertheless, as all the items within a subscale such as Apathy are considered to be measuring the same latent construct, the remaining items should also be measuring that construct. It is notable that of the 16 items in total we removed (from a total of 46) in the FrSBe, five had previously been identified as problematic with factor analysis [34].

Table 1: Psychometric properties of the eight scales employed, showing which items were removed because of poor inter-item correlations, and reliability estimates of the final versions used

Scale	Scale/Feature measured	Number of items retained/removed	Items removed	Mean inter-item correlation (range)	Cronbach's α	Test-retest r
ASRS-Screener	Total	4/2	5,6	0.356 (0.221 - 0.479)	0.688	0.846
FrSBe	Apathy	10/4	16, 38, 39, 41	0.353 (0.147 - 0.689)	0.856	0.851
	Disinhibition	9/6	4, 6, 27, 31, 43, 44	0.258 (0.099 - 0.493)	0.774	0.918
	Executive	11/6	3, 25, 33, 36, 37, 26	0.328 (0.140 - 0.557)	0.824	0.756
SPQ-B	Cognitive-Perceptual	6/2	9, 17	0.358 (0.202 - 0.589)	0.778	0.711
	Interpersonal	7/1	18	0.353 (0.186 - 0.585)	0.793	0.692
	Disorganized	6/0		0.449 (0.257 - 0.601)	0.840	0.809

BIS-15	Motor	5/0		.404 (0.262 - 0.643)	0.806	0.796
	Attentional	4/1	14	0.386 (0.213 - 0.626)	0.708	0.822
	Non-planning	5/0		0.310 (0.182 -0.479)	0.708	0.254
AQ-10	Total	5/5	1, 2, 3, 8, 9	0.213 (0.130 - 0.330)	0.568	0.628
STAI	Trait anxiety	15/5	4, 6, 9, 11, 17	0.338 (0.131 - 0.702)	0.902	0.759
EHI	Handedness	8/2	8, 10	0.327 (0.098 - .709)	0.843	n/a
GHQ-28	Somatic	7/0	n/a	.334 (0.143 - 0.885)	0.807	n/a
	Anxiety/Insomnia	7/0	n/a	.430 (0.208 - 0.634)	0.869	n/a
	Social dysfunction	7/0	n/a	= .449 (0.210 - 0.606)	0.844	n/a
	Depression	7/0	n/a	0.504 (0.226 - 0.731)	0.809	n/a

ASRS-Screener = Adult ADHD Self-Report Scale-V1.1 Screener, FrSBe= Frontal Systems Behavior Scale, SPQ-B = Schizotypy Personality Questionnaire – Brief, BIS-15 = Barratt Impulsiveness Scale-15, AQ10 = Autism-Spectrum Quotient-10, STAI = State-Trait Anxiety Inventory, EHI = Edinburgh Handedness Inventory, GHQ-28 = General Health Questionnaire-28.

We argue that although our procedure resulted in abbreviated scales, the majority of prior work using these scales with normal populations have made no attempt to assess the psychometric properties prior to their application. Our research can there for be seen as demonstrating extra dilligence in not simply assuming that the scales can be transfered across populations.

Although most of the scales performed well, the AQ-10 appeared to have relativly poor psychometric properties in our study. Even with half of the items deleted, the scale still had quite poor internal consistency ($\alpha = 0.568$) and test-retest reliability ($r = .628$). Similarly, the Non-planning subscale of the BIS-15 showed unsatisfactory test-retest reliability ($r = .254$). Consequently, those scales were excluded from Study 2. However, all of the other scales were included. Test-retest reliability was not calculted for the GHQ-28. This is becasue as it considered a measure of transient psychological states, test-retest reliability is uninformative.

Study 2: Associations between neurobehavioral traits and academic achievement

Aims and design

In this study we wished to examine how the various neurobehavioral traits would be associated with academic performance (i.e. GPA) in undergraduate students. We also wished to examine differences based on the subjects studied by the students, to this end we studied two different groups: Psychology undergraduates and Engineering undergraduates. A further interest was whether any associations detected are independent of emotional states or intelligence. To this end correlations were used between the various trait and state measures and intelligence.

Participants

This sample has been reported previously in a study of memory systems and academic achievement [18]. It comprises of 120 undergraduate students at a state university in the city of Riobamba, Ecuador. All participants were studying for undergraduate degrees and had already completed at least three semesters of study when recruited. Half of the sample (n = 60) were students of Educational Psychology and the other half (n = 60) were students of Engineering. There was no difference between the ages of the two groups, $F(1,118) = 1.704$, $p = .190$, $\eta_p^2 = 0.014$ ($M_{Psych} = 22.870$, SD = 2.379; $M_{Eng} = 23.522$, SD = 3.047). Nor was there any difference for socioeconomic status, $F(1,118) = .205$, $p = .651$, $\eta_p^2 = 0.002$ ($M_{Psych} = 3.320$, SD = 1.033; $M_{Eng} = 3.230$, SD = 0.981). There was also no difference in the number of participants from ethnic minorities, as there were 6/54 in both groups. However, as would be expected there was a significant difference in the sex ratios between the Engineering and Psychology groups, $X^2 = 36.310$, $p < .001$ (Engineering 46/60 males, Psychology 13/60 males). We therefore included sex as a covariate in all of the between group and correlational analyses.

Assessments

All participants completed the set of questionnaires described above in Study 1 (ASRS-Screener, FrSBe, SPQ-B, BIS-I5, STAI, AQ-10, EHI, and GHQ28). However, analysis was based on the items and scales shown to have acceptable reliability in Study 1. In order to control for the possible association of intelligence with GPA confounding links to neurobehavioral traits, we also included a brief intelligence assessment. This was the Matrix Matching Test (MMT) which has been shown to be a valid and reliable measure of general intelligence in Ecuadorian adults. In fact, data from the Engineering sample was previously analyzed in the validation study [85]. The MMT is comprised of 24 reasoning tasks, 12 of which are based on semantic ability and 12 on visuospatial ability. It was designed to be a brief measure of intelligence for research purposes and takes around 10 minutes to complete. The internal consistency is acceptable ($\alpha = .748$) with good test-retest reliability ($r = .931$). The test is administered on a tablet computer, with responses recorded manually. One point is awarded for each task answered correctly (maximum 24 points).

As a measure of academic performance, we took the total GPA score over a period of 5 semesters. GPA measures in this university range from 1 to 10 (highest), and so the 5-semester total has a potential range from 0 to 50.

Procedure

All participants were assessed individually in quiet offices at the University where they were recruited. Written informed consent was provided by all participants, in line with the local ethics committee approved protocol. First basic demographic information was recorded and then all participants completed several cognitive tests (reported previously) [18], and also the MMT as a measure of intelligence. The questionnaires were supplied as a booklet and completed by hand during the test session. All students received course credits for their participation.

Statistical analysis

All analyses were performed with SPSS version 23. The distributions of all variables were assessed by examination of their skewness and kurtosis, converted to z scores, and then compared to published criteria for normality of distribution [86]. Where data was approximately normally distributed it was analyzed with psychometric methods (e.g. ANOVA, Pearson correlation). Sex was included as a covariate in all analyses. However, where data were non-normally distributed non-parametric alternatives were used, again covarying for sex, for example non-parametric partial correlations (based on Spearman's RHO) and ANCOVA based on ranked data [87]. For all inferential statistics a significance threshold of 0.05 was employed. Analyses of between group comparisons were all two-tailed, and effect sizes are given as partial eta^2 (η_p^2). For the correlational analyses where directional hypotheses were made (e.g. poor GPA with greater psychopathology or lower intelligence), analyses were one-tailed. Where no direction was predicted two-tailed testing was used (i.e. handedness coefficient and mixed handedness).

Results and discussion of Study 2

In the first analysis the scores from the Psychology students as a group were compared with the scores of the Engineering students as a group. Mean scores are shown in Table 2. The Psychology group had a significantly higher GPA than the Engineering group, $F(1,117) = 92.103$, $p < .001$, $\eta_p^2 = 0.440$. In contrast, the Engineering group were found to score significantly higher than the Psychology group on the MMT, an assessment of intelligence $F(1,117) = 4.850$, $p = .030$, $\eta_p^2 = 0.040$. It is therefore unlikely that the superior GPA of the Psychology group is due to general cognitive ability. Instead it may simply reflect different grading standards in the Psychology and Engineering degree programs. To prevent this GPA difference causing spurious correlations in the later analyses, within the Psychology group only, z scores were calculated for GPA. This was repeated for the Engineering group. This calculation ensures that the two groups have equivalent GPA distributions (mean = 0, SD = 1).

Table 2: Comparisons between Psychology and Engineering students, and associations with academic achievement, for the measures of neurobehavioral traits, current psychological distress state and intelligence

	Mean Scores (+SD)		Correlations with GPA		
Measure	Psychology	Engineering	Psychology	Engineering	Combined sample
n =	60	60	60	60	120
GPA	43.107 (2.155)	37.616*** (2.744)			

MMT	Intelligence	13.433 (3.186)	14.933* (2.968)	-.110	.421***	.154*
ASRS-Screener	Total	10.150 (2.427)	9.933 (2.596)	-.203	-.002	-.087
FrSBe	Apathy	18.750 (4.814)	22.783** (6.230)	-.293*	-.013	-.119
	Disinhibition	58.567 (4.358)	60.850 (5.187)	-.218*	.124	-.014[a]
	Executive	60.283 (4.896)	62.033 (5.149)	-.221*	-.086	-.146
	Total	137.600 (12.260)	145.667* (13.153)	-.281*	.008	-.118
SPQ-B	Cognitive-perceptual	16.250 (3.708)	16.483 (4.601)	-.271*	.142	-.176*
	Interpersonal	20.150 (4.532)	22.867** (4.803)	-.163	-.125	-.137
	Disorganization	15.183 (4.036)	16.783* (4.195)	.113	-.076	.011
	Total	51.583 (9.795)	56.133* (10.283)	-.129	-.152	-.131
BIS-15	Motor	8.033 (2.262)	8.763 (2.938)	-.157	.023	-.042[a]
	Attentional	8.300 (2.157)	9.068 (2.497)	-.188	.131	.004

STAI	Trait anxiety	34.100 (7.679)	35.950 (8.187)	-.147	-.099	-.117
EHI	Handedness coefficient (L-R)	65.972 (47.407)	64.057 (28.553)	-.099[a]	-.135	-.142[a]
	Mixed handedness	24.075 (28.480)	34.693 (25.511)	.210	.178	.122
GHQ-28	Somatic	5.770 (3.543)	6.580 (4.327)	-.246*	-.162	-.184*
	Anxiety/ Insomnia	5.520 (4.339)	7.300** (4.802)	-.225*	-.160	-.205[a],*
	Social dysfunction	4.820 (3.526)	5.920 (3.780)	-.075[a]	-.064	-.062[a]
	Depression	1.250 (2.862)	1.930* (2.629)	-.263[a],*	-.076[a]	-.171[a],*
	Total	17.350 (11.425)	21.733* (12.837)	-.209	-.148	-.159*

*p<.05, **p<.01, ***p<.001, [a]non-parametric partial correlation. MMT = Matrix Matching Test, ASRS-Screener = Adult ADHD Self-Report Scale-V1.1 Screener, FrSBe= Frontal Systems Behavior Scale, SPQ-B = Schizotypy Personality Questionnaire – Brief, BIS-15 = Barratt Impulsiveness Scale-15 (note that the non-planning subscale was not analyzed due to poor psychometric properties in Study 1), STAI = State-Trait Anxiety Inventory, EHI = Edinburgh Handedness Inventory, GHQ-28 = General Health Questionnaire-28.

On the Apathy subscale of the FrSBe, the Engineering group scored significantly higher than the Psychology group, $F(1,117) = 10.576$, $p = .001$, $\eta_p^2 = 0.083$. They also scored significantly higher on the total FrSBe score, $F(1,11) = 5.592$, $p = .016$, $\eta_p^2 = 0.048$. Although there were no significant differences on either of the other FrSBe subscales (Executive or Disinhibition). Regarding schizotypy scores on the SPQ-B, the Engineering group again scored higher than the Psychology group. There were significant differences for the SPQ-B Interpersonal subscale, $F(1,117) = 6.998$, $p = .009$, $\eta_p^2 = 0.056$, the Disorganization subscale, $F(1,117) = 4.690$, $p = .032$, $\eta_p^2 = 0.039$, and the Total score, $F(1,117) = 5.237$, $p = .024$, $\eta_p^2 = 0.043$. However, there was no significant difference on the Cognitive-perceptual subscale.

Regarding the mental health status measures on the GHQ-28, again the Engineering group scored higher than the Psychology group on several indices. These were: Anxiety/insomnia, $F(1,117) = 8.812$, $p = .004$, $\eta_p^2 = 0.070$, Depression, $F(1,118) = 5.628$, $p = .019$, $\eta_p^2 = 0.046$ and the Total GHQ-28 score, $F(1,117) = 5.481$, $p = .021$, $\eta_p^2 = 0.045$.

There were no significant between-group differences for any of the other measures, although the Engineering group scored somewhat higher for trait anxiety on the STAI, and this small difference had a trend toward significance, $F(1,117) = 3.528$, $p = .063$, $\eta_p^2 = 0.029$. In summary then, the Engineering group appeared to score significantly higher on a test of intelligence, but also on several measures of neurobehavioral traits and mental health states, on which higher scores indicated greater risk of pathology.

In the second phase of analysis we examined the correlations between scores on the various measures and GPA. This was performed for both groups individually, as well as for the combined group (N = 120). The coefficients are also shown in Table 2. Examining the Engineering group first, it is notable that the only significant correlation with GPA was for the MMT, the measure of intelligence. This was also a relatively strong relationship, at r = .421 it was the strongest of all the relationships explored in Table 2. In contrast, there appeared to be no statistical association between the Psychology group GPA scores and the measure of intelligence. However, again in contrast with the Engineering group correlations, for the Psychology group there were several significant associations between the neurobehavioral traits and mental health states with GPA. These associations are all of the scales on the FrSBe, the Cognitive-perceptual scale on the SPQ-B, and three of the four subscales on the GHQ-28 (Somatic, Anxiety/insomnia, and Depression). Comparing the broad pattern of correlations between the two groups, it appears that intelligence is associated with engineering study success while neurobehavioral traits and mental health status are associated with psychology study success.

In the Psychology group, as there were associations between GPA and neurobehavioral traits, and also with psychological distress as a state measure (the GHQ-28), it may be that the neurobehavioral trait associations are confounded by the psychological distress state. All the correlations shown involving neurobehavioral traits for the Psychology group in Table 2 were recalculated, but with GHQ-28 total scores added as a covariate. In this analysis, correlations of GPA with Disinhibition, Executive dysfunction and Total scores on the FrSBe became non-significant. However, two scales did remain significantly associated with GPA: Apathy scores on the FrSBe ($r = -.220$, $p = .049$, and Cognitive-perceptual scores on the SPQ-B ($r = -.236$, $p = .037$).

In the Engineering group, as there were no associations between GPA and psychological distress states, but there was with intelligence, all of the correlations from Table 2 were repeated with intelligence test scores entered as a covariate. This did not change any of the original correlations from non-significant to significant.

We also examined the effect in the combined sample of covarying psychological distress states with the GHQ-28, and intelligence tests scores, as both GHQ-28 scores and MMT scores are significantly correlated with GPA. Before adding GHQ-28 and MMT scores as covariates, there was just one significant correlation between a neurobehavioral trait and GPA, as shown in Table 2 this with the Cognitive-perceptual scale on the SPQ-B ($r = -.176$, $p = .028$). The magnitude of this association is diminished and no longer significant with GHQ-28 and MMT scores covaried ($r = -.143$, $p = .063$). Interestingly, when GHQ-28 and MMT scores are covaried one of the measures that was not previously significant in the whole sample, Mixed-handedness, was found to be significantly associated with GPA, $r = .204$, $p = .028$. As a positive correlation, it suggests greater mixed-handedness is associated with higher GPA. It is also notable, that this seems to not be driven simply by one of the groups, as both the Engineers and Psychology groups showed this association to some extent when potential confounds were covaried (Engineers $r = .193$, $p = .153$; Psychologists $r = .203$, $p = .127$). Admittedly, in neither case was the correlation significant, but this is partly because the sample sizes are only half that of the combined sample.

Overall, the results suggest that the correlates of academic performance are different between the Psychology and Engineering groups. Emotional states and neurobehavioral traits (i.e. apathy and positive symptoms measured by the Cognitive-perceptual measure of schizotypy), but not intelligence, are associated with performance of the Psychology students. More or less the opposite is true of the Engineering students. As a whole group (Psychology and Engineering students combined), perhaps approximately representative of university students in general, emotional states and intelligence have some impact on grades, as does mixed-handedness.

General discussion

It is tempting to think that there may be specific neurocognitive functions or neurobehavioral traits which link neuroscience to academic achievement in general, at least within defined groups such as undergraduate students. The most common way that this way of thinking is manifest is in terms of intelligence. However, the current results indicate that such an approach is likely to be quite limited. One reason for this is that students studying for different majors do appear to differ from each other. In the current results our two exemplar groups, Psychology students and Engineering students, chosen to represent two different types of study, differed significantly in terms of intelligence, neurobehavioral traits and susceptibility to psychological distress states. In fact, the Engineers tended to have higher scores on the test of intelligence, and also tended to report higher scores indicative of pathology on several of the neurobehavioral trait and current psychological distress status scales. These inter-subject differences are likely to impact on academic performance.

Whereas for school children, there are highly replicated associations between neurocognitive performance and achievement, particularly for working memory [16, 17], this result does not extend well to higher education [19, 20]. One key difference is that students within different majors at university level are to a large extent self-selecting: students choose to study what they want to study. This is general not true of lower-level education. This is probably the reason behind the inter-subject differences reported here.

For the Psychology students there were several neurobehavioral traits associated with academic performance. In particular, the traits associated with prefrontal-subcortical systems and measured with the FrSBe were all correlated with academic grades, with higher (more pathological) scores associated with lower GPA. These were the scales of Disinhibition, Executive dysfunction, and Apathy. Although, some of this association was likely confounded by psychological distress states, which were also linked to GPA, again, higher (more pathological) scores associated with lower GPA. Nevertheless, when psychological distress state scores were covaried, Apathy remained a significant correlate of academic achievement. This was also true of the positive symptoms scale of schizotypy (Cognitive-perceptual), raised levels of which were significantly associated wither lower academic performance, even if the potential confound of current psychological distress states was controlled for statistically. On the other hand, there appeared to be no association between intelligence and academic performance of the Psychology group.

These results contrast sharply with those found in the Engineering group. In this case, intelligence is an important and relatively strong correlate of academic achievement. However, neither neurobehavioral traits, nor psychological distress states appeared to have any association with grades. One could hypothesize that intelligence is important in technical subjects such as engineering, but less so in social science subjects such as educational psychology. Inter-personal and behavioral traits and states might be more important in social and psychological subjects. Our findings are consistent with that interpretation. Such associations have previously been reported in younger students, at pre-university level, in which intelligence was more important than personality in the prediction of science grades, while the opposite was true for literature and language studies [88].

An important implication of this is for student selection. It is not uncommon for university entrance to be partly decided by performance of intelligence tests. Our results suggest that while this may have some merit for the selection of candidates to study engineering and perhaps other technical subjects, it is likely to be useless in the selection of candidates to some other subjects, at least to the extent that the selection is for those likely to succeed in their studies.

If we accept that intelligence and neurobehavioral traits have differential associations with academic achievement depending on subject matter, it becomes expedient to explore why the different factors associate with academic achievement. For intelligence this is not controversial, standard definitions such as *"Intelligence is a 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."* p. 13 [89] seem to be consistent with the goals of education. Indeed, academic achievement of university students is often used to validate intelligence tests [85]. Furthermore, intelligence appears to be a rather general measure of ability. This is evinced by the 'positive manifold'- the observation that all cognitive tests appear to be positively correlated, suggesting a basic underlying biological bases that affects all aspects of cognitive functioning [90]. Indeed, intelligence, and academic performance, are both positively associated with global white matter connectome connectivity as measured by fractional anisotropy, but not any specific tract or region [91]. This also suggests that assessments of intelligence capture a rather general feature of neurocognitive efficiency, one manifestation of which can be ability in higher education. Although this may explain why intelligence was associated with academic attainment in the Engineering group, it does not explain why there was no relationship in the Psychology group.

Part of the reason may be that university students are already selected for ability, so there is relatively limited range, and the differences in intelligence scores that exist may not be wide enough to have much influence on grades. This would be particularly true if within courses such as psychology, educators emphasize interpersonal and self-control aspects. There is indeed evidence that the development of inter-personal skills such as teamwork, leadership, time-management, self-confidence etc. are seen as particularly important by psychology educators [92]. This may explain why in regard to academic achievement of psychology students, neurobehavioral traits appear to be more important than intelligence in the current research.

However, why Apathy and positive schizotypy are particularly associated with academic achievement of psychology students requires further explanation. Regarding Apathy, a simple explanation for the link to grades is that high motivation to achieve is already known to be associated with academic attainment, including in samples of psychology undergraduates [93]. In the current study we did not measure motivation to achieve, but a more general trait of motivation, or its opposite- apathy. This scale contains items such as "Has difficulty starting an activity, lacks initiative, motivation" [36], and participants rate how true they think the statements are about themselves. One could see how students with high apathy as a personality trait may fail to flourish in higher educational contexts.

On the other hand, our research is purely observational, and it is perhaps equally possible that poor grades produce a feeling of apathy, or of course many other mediating factors could be involved. Nevertheless, the scale that we used was specifically designed to measure functioning associated with the integrity of a particular prefrontal-subcortical circuit, specifically the anterior cingulate circuit which projects ipsilaterally to the ventral striatum and looping back to the original area of innervation via the rostrolateral globus pallidus interna and the mediodorsal nucleus of the thalamus [39]. The cortico-striatal-thalamic aspect forms the core of the loop, but it is also known to have many afferents from other parts of the limbic system including the hippocampus, amygdala, and entorhinal and perirhinal cortices [47].

The role of this circuit in motivation, and as a pathology of motivation, is frequently observed in clinical studies [40, 43, 94], but its role in motivation is also supported by experimental work with animals [95]. It seems reasonable to assume that the Apathy scale that correlates with GPA in the current research is measuring what it was designed to do, i.e. some aspect of activity in the anterior cingulate-subcortical circuit. Interestingly, a recent study which used functional brain imaging of cognitive control tasks with medical students as participants reported that the students' grades were positively correlated with activation of the anterior cingulate cortex (but not with other areas such as the dorsolateral prefrontal cortex) [96]. Our research is consistent with this imaging study, with both suggesting a role for the anterior cingulate subcortical circuits in the type behavioral control that is linked to academic achievement in higher education.

Regarding positive schizotypy, i.e. scores on the Cognitive-perceptual scale of the SPQ-B, the reason that scores correlate with academic performance may simply be that, although the trait is distributed evenly within the normal population, it is clearly a trait that predisposes to cognitive impairment. This is known because the same cognitive difficulties that are seen in frank schizophrenia are also seen in individuals who score high on the cognitive-perceptual scale, and indeed scores correlate with the magnitude of the cognitive difficulty [55]. In addition, longitudinal research has shown that high positive schizotypy in young people is associated with various long-term maladjustment issues, including substance abuse, mental health treatment and suicide attempts [21]. Interestingly, one of the neural features associated with positive schizotypy, even in psychologically healthy young people, is reduced white matter in several frontal-temporal tracts, but particularly involving the forceps minor [97]. This white matter tract links the anterior cingulate cortex with lateral and rostral prefrontal cortices [98] and hence forms part of the anterior cingulate circuit described above in relation to apathy. Again, reinforcing previous work suggesting that anterior cingulate activity may be linked to academic achievement [96].

Although there were differential associations between intelligence on the one hand and neurobehavioral traits of apathy and positive schizotypy on the other in association with engineering and psychology grades, there was only one feature which appeared to be associated with academic grades irrespective of subject matter. This was mixed-handedness. Basically, being either strongly left- or right-handed was associated with poorer grades, being more ambidextrous was associated with higher grades. That it is mixed handedness, not perhaps right-handedness, driving the effect is shown by the lack of association with grades in the normal left-right coefficient of the scale used to measure handedness. Only when we produced a scale ranging from low scores to high scores for mixed handedness was the association revealed.

Why mixed handedness should be associated with achievement is difficult to explain at present as the evidence on the relationship of handedness to both cognitive ability and real-life academic attainment is equivocal. In children, mixed-handedness is associated with poor academic performance, but this is mainly observed in fully-mixed handed pupils, i.e. those with no preference at all for either their left or right hands. This was shown in one of the best studies in the field which included 12,770 participants, those with no left-right preference i.e. at the 'hemispheric indecision point' achieved much lower verbal, non-verbal, reading comprehension, and mathematics grades. However, in the same analysis, being fully right-handed was also associated with poor academic performance, compared to being only mainly right handed [78].

In adults at least, and in the usual participants in cognitive studies, undergraduate students, mixed-handedness is associated with better declarative memory performance. Furthermore, this is evident even in incidental learning paradigms, suggesting it is true effect of declarative memory ability, rather than being caused by factors such as motivation or strategy use [77]. This may be one way in which mixed-handedness could convey a small advantage in higher education. We have previously shown in the same sample as reported here, that the modulation of memory processes is a significant predictor of academic grades [18]. In addition, a study of foreign language acquisition, that mimicked natural language learning, found that the amount of learning was proportional to degree of mixed-handedness of the participants [99]. This therefore shows how the aforementioned better declarative memory skills of mixed-handed individuals, compared to those with strong hand preferences, may go beyond performance in laboratory studies, and contribute to academic achievement.

Possible biological mechanisms underlying the association of learning and memory performance with mixed-handedness are the observed larger corpus collosum [100], and greater right frontal lobe activation [101] in mixed-handed individuals, compared to those who strong hand preferences. These biological differences have been suggested to enhance episodic memory based on a neuropsychological model that emphasizes interhemispheric communication, with an important role for right frontal lobe processes in recall [102]. This involvement of right frontal lobe processes is consistent with our previous finding that neuropsychological assessments linked to right prefrontal function outperform measures on intelligence on predicting student GPA [19].

An alternative explanation for the observed association between mixed-handedness and academic grades could be because mixed handedness shows some left-right asymmetry. Using dichotomous categorization into mixed handedness and strong handedness, people with an overall preference for the left hand, compared to those with an overall right-hand preference, tend not to be strongly left-handed, i.e. left-handed people display greater mixed handedness [102]. In addition, a general tendency for left-hand preference, either mixed or strongly left-handed is overrepresented in youths with extremely high scores on academic ability such as the Scholastic Assessment Test (SAT) used for college admission in the USA

[103]. However, we feel this is unlikely to be driving the current results that show mixed handedness correlates with GPA for several reasons. Firstly, left-handedness is also over represented in intellectually disabled individuals compared to individuals with neurotypical development [79]. Consequently, mixed handedness with a left preference is overrepresented at both extreme high and low levels of intellectual ability. Secondly, large studies with thousands of participants have reported that there is no, or only a negligible difference, on intelligence test scores between those classified as left or right-handed [104, 105]. Thirdly, we found no association with grades when examining handedness on a left-right gradient. The significant association was only present for degree of mixed-handedness. It therefore appears that simple left-right analyses fail to capture the effect of handedness on individual differences in cognitive performance and academic achievement. The simpler explanation for the current results is that it is the degree of handedness (ranging from strong to mixed preference), rather than direction of handedness (ranging from left to right), that is important. This is consistent with other recent work that emphasizes that degree not direction of handedness is more informative for the interpretation of behavioral and biological data [100, 102].

Nevertheless, one possible problem encountered when considering handedness on a continuum from strong preference to mixed handedness, is the previously mentioned research that showed that being very strong mixed-handed is associated with poor school grades in children [78]. This is the opposite of our finding with university students. This discrepancy is not necessarily a problem for the current findings. The study with children found that poor school performance was associated with being ambidextrous, i.e. having very little preference at all for use of their left or right hands. Although such individuals are definitely mixed-handed, the represent minority of mixed-handed individuals. Furthermore, in the same data set it was shown that strong hand preference was also associated with lower academic performance, which is consistent with the current results.

Admittedly, the correlations between mixed-handedness and grades in the current research are quite low, and technically ‘small’ in magnitude [106], at around 0.2 for either of the subgroups, or the combined sample. In fact, most of the significant correlations reported here are technically ‘small’. The one exception being the correlation between intelligence tests scores and grades in the Engineering group, which at 0.421 is ‘medium’ sized. However, it should be noted that correlations of cognitive ability with academic performance at university level are frequently small, in fact the mean correlation effect size from a meta-analysis of intelligence test performance in predicting university grades estimated a mean of effect size of only 0.2 [24].

The detection of small correlations requires relatively large sample-sizes. In the current research only 120 students participated. The chance of type ii errors is therefore quite high. Further research could involve a much larger sample. On the other hand, a strength of the current research is the inclusion of a one-to-one administered intelligence test, which was used mainly to provide a control variable for interpretation of the neurobehavioral data. A further strength is that we ascertained the reliability of the neurobehavioral scales used, an in fact adjusted them to ensure unidimensionality. Although the use of clinical scales such as the FrSBe in non-clinical populations is always problematic, we are confident that the reduced scales employed in this research were psychometrically sound in terms of reliability. However, it should be noted that we did not do any assessment of validity for the different scales, and therefore it could be argued that what we measured here is not the same as is being measured when the assessments are used in clinical groups. Nevertheless, the majority of work which uses clinical scales in this way simply assumes that the scales can be transferred to non-clinical use. We went somewhat further in establishing reliability.

Conclusions

Despite some limitations, we are able to reach tentative conclusions in this essentially exploratory research. Firstly, the individual difference factors associated with success in higher education vary, depending on the group/subject matter. Secondly, intelligence may be important in technical subjects such as engineering, but mental health and behavioral trait factors seem less important. The opposite may be true in more social science-based subjects such as Psychology. In particular, positive schizotypy and apathy may be particularly associated with (poor) academic grades. Finally, mixed-handedness may be associated with academic success in higher education, regardless of group/subject matter.

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