# ABO Blood Group, Socioeconomic Status, and Cognitive Function: Evidence from College Students for Better Visual Recognition Associated with the Type O Phenotype

Graham Pluck

*Faculty of Psychology, Chulalongkorn University*
*graham.ch@chula.ac.th*

## Abstract

The ABO blood group system is associated with neurological health and cognitive impairment, and also with structural differences in the healthy human brain. The current research aimed to examine how blood group may be associated with cognitive functioning in non-clinical participants. Participants were 132 students at two universities in Ecuador. All were assessed for blood group and a range of cognitive abilities with known neurological substrates: shape recognition ('ventral visual route'), spatial vision ('dorsal visual route'), language-syntactical processes (left perisylvian), focused attention (right perisylvian), executive function (dorsal prefrontal), advantageous decision making (ventral prefrontal) and declarative (medial temporal) and procedural (basal ganglia) learning. Socioeconomic status (SES) was assessed as a potential confounding variable. Preliminary analyses revealed that ABO blood type frequencies showed a cline, varying by site of data collection, and Type O blood was more common in participants from lower SES backgrounds. Additionally, higher SES was associated with better cognitive performance. Significant positive correlations were found indicating associations between higher SES and better performance on tasks of language, and executive function, and for declarative and procedural memory processes. With SES and data-collection site covaried, precategorical visual shape recognition task performance was

Received 14 October 2020; Revised 24 October 2022; Accepted 03 November 2022
*Journal of Cognitive Science* 23(4): 493-524 December 2022

observed to be the only factor significantly associated with blood group, being better in participants with the Type O phenotype. This result was present in two different samples and was significant with or without the use of covariates. I conclude that, in this sample from Ecuador, human blood group classification was linked to variability in adult human neurocognitive function, specifically, shape recognition task performance associated with occipito-temporal processing. This may have implications for understanding variation in neurological and cognitive health, as well as cognitive abilities as individual differences, and potentially provides a biomarker for efficiency of human object-recognition skill.

**Key words:** *cline, cognition, socioeconomic status, vision, ABO blood groups, visual recognition*

## 1. Introduction

The human brain requires a substantial and continuous flow of oxygenated blood, consuming about 20% of the body's oxygen supply despite only being about 2% of the total body mass (Rolfe & Brown, 1997). In addition, rate of cerebral blood flow is positively associated with intelligence (Kilroy et al., 2011), and intelligence can be seen as an indicator or neural processing efficiency (Langer et al., 2012).

Although often conceptualized as separate systems, the neurons and vasculature of the brain are extremely closely linked, anatomically and functionally. There is substantial inter-communication between neurons, glia, and blood vessels, to the extent that they can be seen as a functioning together as homeostatic components. Indeed they are often described as being *neurovascular* units (del Zoppo, 2010) or as a *neurovascular complex* (Schaeffer & Iadecola, 2021). This approach aims to acknowledge and understand how changes to any component of a neurovascular

unit influences the functioning of the whole unit. Practically, this close neurovascular coupling allows for the measurement of cognition-related neuronal activity with functional magnetic resonance imaging (Sumiyoshi et al., 2019). It is also an important mechanism, in pathology, of cognitive impairment associated with dementia and other brain disorders (Schaeffer & Iadecola, 2021). Loss of neurovascular coupling and vascular integrity are also associated with metabolic disorders (such as obesity and diabetes), among many other changes to the neurovascular system, which can produce cognitive impairment (Coucha et al., 2018).

Clearly there are many ways that variation in the blood supply to the brain influences neural processing and cognition. This is a complex physiological system, but one important component may be the composition of red blood cells and plasma. Blood group classification, as used to assess safety of transfusions, is based on the genetic inheritance of alleles coding for two different enzymes which modify a basic antigen that all people have on the surface of red blood cells. Individuals may inherit either or neither, producing three different forms of the antigen. As individuals inherit pairs of genes that may individually lead to the expression of either, both, or neither, this produces six different possible genotypes. These yield four different phenotypes, Type O, Type A, Type B and Type AB. Type O is characterized by the absence of both of the antigen modifications, while the other phenotypes have combinations that include at least one of the modified forms (Lodish et al., 2008).

This variation in phenotypes influences plasma levels of a glycoprotein called von Willebrand factor. Importantly, people with the Type O blood phenotype have 25-30% less of this coagulation factor compared to non-O individuals (Jenkins & O'Donnell, 2006). This has clinical relevance because plasma levels of von Willebrand factor are mildly predictive of coronary artery disease in non-clinical samples, and substantially predictive of outcome in already identified vascular disease patients (Spiel et al., 2008).

Indeed, this difference in levels of a coagulation factor may be why Type O individuals, compared to non-O individuals, are at reduced risk for a wide range of cardiovascular illnesses. For example, it is suggested as the reason why Type O individuals are at reduced risk of coronary artery disease and myocardial infarction (Chen et al., 2016), and peripheral artery disease (Pike et al., 2017). One longitudinal cohort study found that 8.9% of all mortality due to cardiovascular disease was attributable to non-O blood phenotypes (Etemadi et al., 2015).

It could, therefore, be assumed that neurological health would also be associated with individual variation in blood physiology. Indeed, there is evidence that being Type O is protective of the development of ischemic stroke (Sabino Ade et al., 2014; Wiggins et al., 2009). A recent study showed that adults over age 45 with Type AB blood were at increased risk of cognitive decline when compared to individuals with Type O blood (Alexander et al., 2014). In addition, older people with Type O blood seem to develop less postoperative cognitive dysfunction following surgery (Li et al., 2017). This suggests that being Type O may be a protective factor in the development of dementia. Furthermore, there is evidence that psychiatric disorders are related to Type AB blood, with a trend to Type O being a protective factor (Pisk et al., 2019). Overall, the results seem to suggest better clinical-neurocognitive prognosis in individuals with Type O blood compared to other phenotypes.

In addition, there is evidence for structural brain differences between individuals with Type O and non-O blood. On structural magnetic resonance imaging (MRI), Type O individuals, compared to non-O individuals, have larger volumes in areas of the posterior ventral cerebellum and anterior temporal lobes bilaterally, and larger regions of the left hippocampus and right uncus (De Marco & Venneri, 2015). The reasons for these structural differences are not known. It is possible that they are related to the availability of von Willebrand factor and its impact on circulation.

Alternately, the antigens of the ABO blood group system are not only found on red blood cells, but also on some neurons (Gil-Loyzaga, 1997; Mollicone et al., 1986), and this could potentially influence the brain directly.

Given the associations of blood group, specifically Type O, being protective of cognitive impairment and associated with brain structure, it might be expected that there are associations between Type O blood phenotype and better cognitive function in healthy samples. However, evidence either way for this is sparse. In one large study comparing ABO phenotypes, as well as several other blood classification systems, it was suggested that increasing homozygosity (such as Type O) is associated with better verbal and spatial test performance, but not with speed of processing of memory tests (Ashton, 1986). However, the authors stress that effect sizes are very small and of doubtful practical significance. It may be that more focused cognitive tests, based on known neurocognitive systems, would be better at identifying what could be variations in quite specific processes. Unfortunately, the existing research on this has used general, non-biologically-informed approaches to cognitive ability.

A study in the UK suggested a link between intelligence test scores and blood phenotype, with higher scores observed in people with a subtype of the A phenotype, $A_2$, and the O phenotype, when compared to individuals with the $A_1$ phenotype (Gibson et al., 1973). However, the results of the research have not been replicated, and have generally been discounted due to research weaknesses which confound interpretation. In particular, socioeconomic status was not considered. This is important because blood group phenotype has possible ethnic and socioeconomic correlates.

Some studies have revealed no link between socioeconomic status and blood type, such as one in Ireland (Kelleher et al., 1990). However, the current research was conducted in South America, where this is unlikely to be the case. This is because before the arrival of conquistadors in the early 16th century, the indigenous population appear to have been almost

completely of the Type O phenotype. This is known from genetic analysis of pre-Columbian human skeletal and mummified remains (Halverson & Bolnick, 2008; Llop & Rothhammer, 1988). In contrast, the European colonists had much greater variance, including the A and B alleles. To this day, native populations in the Americas have a high rate of O phenotype compared to most other groups worldwide (Delaney et al., 2015; Sanchez-Boiso et al., 2011). Native populations in Latin America also suffer greater socioeconomic hardship compared to those with colonial heritage, including Mestizos, i.e., those with mixed Native American and European ancestry (Hall & Patrinos, 2012). Therefore, it is anticipated that in our samples from Ecuador, ABO blood group phenotype will be associated with socioeconomic status and that could obscure relationships between blood phenotype and cognitive ability, as socioeconomic status is consistently found to be linked to cognitive ability (Farah, 2017; Pluck et al., 2021).

In the current research, I examined how human blood group phenotypes, either Type O or non-O (i.e., A, B, or AB) are associated with cognitive functioning. Although there is evidence for the influence of blood group on neurological health and brain structure, there is no clear evidence for effects on cognitive function, nor for which cognitive functions might be implicated. Therefore, I took an exploratory approach, examining eight different functions associated with specific neural substrates, and widely accepted in cognitive neuroscience. In addition, socioeconomic status was considered as a potential confounding variable.

## 2. Method

### 2.1 Design

This research used a quasi-experimental, and exploratory approach, comparing participants divided into two phenotypic groups, those with blood Type O and those with non-O blood Type (i.e., A, B, or AB). Rhesus

factor was not considered. In Ecuador, where this research was conducted, most adults know their own blood type, as it is included on various national documents, such as driving licenses. Thus, self-report was used to classify participants to a group, Type O, or non-O. Although clearly not as direct a measure as a laboratory test to establish blood type, studies suggest that self-reported blood group tends to be in almost perfect agreement with DNA-derived ABO blood group categorization (Bider-Canfield & Cotterchio, 2014; Ito et al., 2001). The two identified phenotypic experimental groups (Type O and non-O) were compared on performance of 8 different cognitive tests, designed to assess a range of neurocognitive functions, i.e., cognitive functions with relatively well-accepted anatomical bases.

### 2.2 Participants

All participants were undergraduate students at two universities in Ecuador. Two different universities were sampled in order to extend the ranges of the variables in question. The majority of the data reported here were collected in a publicly funded university in Riobamba which serves a relatively low socioeconomic background demographic. However, a smaller sample was also collected in a prestigious private university in the city of Quito, which serves a relatively high socioeconomic demographic.

From the public university, 120 participants were recruited. However, of those 120, data on blood group was not reported or was misrecorded for 14 participants. The remaining 106 cases had full data. The mean age of this sample was 23.17 (SD = 2.80), and 51/106 (48%) were female (by self-report). Ethnically, one identified as being white, one as Afro-Ecuadorian, and six (6%) identified as being Indigenous Americans. The remainder all identified as being Mestizo, 98/106 (92%). From the private university, 26 participants were recruited, and blood group was recorded for all 26. The mean age of this sample was 21.55 (SD = 1.56), and 19 (73%) were female (by self-report), and all identified ethnically as Mestizo. The combined

sample, therefore, comprised 132 participants (70 female), and the mean age was 22.85 (SD = 2.68). The majority, 74/132 (56%) were psychology majors.

In both groups, socioeconomic status was established based on demographic data of the participants' family background (e.g., education level and occupation), in accordance with criteria used in the most recent Ecuadorian census (Instituto Nacional de Estadística y Censos, 2011). This identifies 5 socioeconomic strata ranging from 5 - 'high' stratum, comprising the 2% of the population at the highest socioeconomic privilege, to 1- the lowest stratum comprising 15% of the population at the lowest level of socioeconomic privilege. For the public university participants, the modal socioeconomic stratum was 3 (range = 1-5), which is much lower than in the private university in which the modal stratum was 5 (range 4-5). In fact, 22/26 (85%) participants in the private university sample were in the highest socioeconomic stratum, compared to only 2/106 (2%) in the public university sample.

### 2.3 Cognitive Assessments

There is no consensus on how to parse the human cognitive system into separate subsystems and no single assessment battery providing a wide scope of functions. To sample a wide range of functions I applied four different dichotomies, widely accepted within cognitive neuroscience, to identify eight relatively independent cognitive functions, with generally accepted broad neurological substrates. These are detailed below.

*Shape Recognition and Visuospatial Processing*

The first dichotomy is the separation of occipital lobe visual processing into object recognition and spatial-action processing streams, projecting ventrally to the temporal and dorsally to the posterior parietal cortices respectively (Goodale & Milner, 1992).

In order to measure performance related to the ventral object recognition system, I adapted a recognition test that has previously been shown to activate a key part of the ventral stream, the lateral occipital complex (LOC), during functional MRI in healthy participants, as well as being sensitive to impairment in a patient with visual-form agnosia who has selective damage to the same area (Cavina-Pratesi et al., 2010). The same shape recognition stimuli materials from that study were used here. These comprised of representations of cuboids, cylinders and ellipsoids which varied in length, but all had the same volume and texture. In each trial, three shapes were presented simultaneously for two seconds on a tablet computer screen, in a vertical column, and either the top shape or the bottom shape was identical to the middle shape. The participant's task was to say which was identical to the middle shape, ‘upper’ or ‘lower’. There were three practice trials followed by 42 data collection trials.

To measure performance related to the dorsal visuospatial system, I used a 3-D block design task (Benton et al., 1994). The tasks and scoring procedure used here are detailed in Benton et al. (1994). In this research, only the tasks requiring construction in three dimensions (trials 2 and 3) were scored.

*Language and Attentional Biases*

The second dichotomy is the neuropsychological distinction between a left-lateralized perisylvian language system (Catani et al., 2005) and a right-lateralized perisylvian system for focused visual attention (Karnath, 2009).

To measure language function, I used an adaptation of the Northwestern Anagram Test. This test is usually used to measure processing of syntax in aphasic patients and is sensitive to aphasia severity but not with measures of object recognition, naming, or single word comprehension (Weintraub et al., 2009). As it was expected that accuracy would be very high in my non-clinical sample, time to completion of each sentence was recorded. These were summed to give an overall measure of syntactic processing speed.

To measure focused attention, I used a neuropsychological test based on one that can detect either egocentric or allocentric forms of attentional bias-the Circle Discriminative Cancellation Task (Ota et al., 2001). I included 80 complete circles as distractors, with 40 left-gap circles and 40 right-gap circles as targets distributed randomly on an A4 piece of paper (presented in landscape), but with equal numbers on the left and right sides of the page. The participant is asked to use a pen to cross out as many of the incomplete circles as possible. They are given 30 seconds, which is insufficient time to complete the task. Two trials were completed. The number of left page stimuli crossed minus right page stimuli crossed was then calculated, with negative numbers made positive. This was used as the egocentric attention measure. The number of left-gap circles crossed minus right-gap circles was calculated, with negative numbers made positive. However, the scale was then reversed (calculated as 1-scores) so that higher scores indicated better (more left-right balanced) performance.

*Declarative and Procedural Memory*

The distinction between declarative and procedural memory has been used clinically to explain various dissociations between patients with medial temporal lobe damage and patients with basal ganglia disorder. This dichotomy suggests that somewhat separate memory systems exist for declarative knowledge in the medial temporal lobe and procedural learning in the basal ganglia (Knowlton et al., 1996).

To measure declarative memory, I used an incidental learning task in which participants viewed pairs of abstract designs in which one was slightly smaller than the other. The task was ostensibly to identify which was larger. However, the 27 different designs were presented in a surprise recognition test approximately 90 minutes later. A detailed description of this test is given in Pluck et al. (2019) which includes analysis of the memory test scores of a subsample of the participants included in this study.

To measure procedural memory, I used a probabilistic classification task, the Weather Prediction Test. This test has previously been used to demonstrate impaired procedural learning in patients with basal ganglia disease in contrast with preserved performance in patients with declarative amnesia due to medial temporal lobe damage (Knowlton et al., 1996). The contingency and stimuli pairings used in this study were taken from the study by Kincses et al. (2004). Participants completed 50 trials. The number of correct weather predictions in the final 20 trials was taken as the measure of learning.

*Executive Function and Advantageous Decision Making*

The final dichotomy is between higher-level cognitive processes associated with the prefrontal cortex. These are commonly divided into those that are mainly executive in nature, associated with dorsal regions, and those in which emotional and motivational cues are integrated into decision making, associated with more ventral regions (Glascher et al., 2012; Rahm et al., 2013).

To measure dorsal prefrontal associated executive functioning, I used the Design Fluency task from the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001). The total score is the sum of unique designs over three trials.

To measure ventral prefrontal associated decision making with rewards and punishments, I used the Iowa Gambling Task (Bechara et al., 1994). This is one of the most widely used tests of neuropsychological decision-making impairments associated with ventral prefrontal damage (Bechara et al., 1994; Bechara et al., 1997). Participants are required to partake in a gambling game in which they choose cards from four piles. Equivalent to the original version of this test, I used facsimile dollar bills. However, I used fewer trials, only 45, as performance past this point is thought to involve greater executive processes, and is less specific to ventral prefrontal

function (Ouerchefani et al., 2019). As the measure of advantageous decision making, I counted the number of choices from the 'good' decks in the final 25 of the 45 total trials.

**2.4 Procedure**

All participants were tested in face-to-face sessions in a quiet room at the respective university. Informed written consent was obtained from all participants, in accordance with the research protocol approved by the Bioethics Committee of Universidad San Francisco de Quito. Background data such as socioeconomics and blood group were collected first, and then all eight of the cognitive tests were administered. Most of the tests were administered with 10-inch Samsung Galaxy tablet computers to display stimuli, but with responses recorded by hand. After the final assessment (the declarative memory recognition test), participants were debriefed and thanked for their help. All participants received course credits for taking part in the research study.

**2.5 Statistical Analysis**

Normality of data distributions were assessed by examination of the kurtosis and skew, according to published criteria (Kim, 2013). Distributions that were not normal were transformed with RANKIT procedure (Soloman & Sawilowsky, 2009), producing normal distributions in all cases, and were thus analyzed with parametric procedures (transformed variables are indicated in Table 2). Analyses with ANOVA, $Chi^2$ and correlations were used to identify potential confounding factors. The main analyses compared people with the Type-O phenotype with people with non-O phenotypes, using ANOVA, with covariates as necessary to control for confounds. All analyses were two-tailed with a significance threshold of 0.05. Due to the exploratory nature of the research correction for multiple comparisons was not applied, however, secondary analyses were applied to assess the

robustness of differences found to be statistically significant. To compare effect sizes, $\eta_p^2$ has been used for ANOVA calculations, defined as 'small' > .0099, 'medium' > .0588, and 'large' > .1379 (Richardson, 2011).

## 3. Results

### 3.1 Analysis of Demographic Factors and Potential Confounding Variables

Of the 132 participants the majority were Type O blood group (94/132, 71%). Next most common was Type A (25/132, 19%), Type B (10/132, 8%) and then Type AB blood groups (3/123, 2%). In this research, I compared the 94 Type O participants with all of the others, known here as the non-O group. Table 1 shows the demographic features of the two phenotypic groups.

Two significant differences were observed. As a group, the non-O participants had significantly higher SES, $p < .001$, and were significantly more likely to have been recruited at the private university in Quito than the Type O participants, $p = .002$. These two factors are in fact closely related, the private university students were of a significantly higher socioeconomic background, with a mean SES score of 4.84 (SD = 0.37) compared to the public university sample with a mean SES score of 2.75 (SD = 0.98), $F(1,130) = 115.738$, $p < .001$, $\eta_p^2 = 0.471$. Nevertheless, the two measures are not redundant indices of socioeconomic situation. If the comparison for SES scores between the phenotypic groups is repeated with university (private or public) entered as a covariate, the SES score difference is attenuated but not removed, with adjusted means of 3.06 (SEM = 0.09) for the O group, and 3.39 (SEM = 0.15) for the non-O group, $F(1,129) = 3.496$, $p = .064$, $\eta_p^2 = 0.026$.

**Table 1.** Comparison of the two phenotypic blood classifications (O or non-O) for demographic factors

| | O | Non-O | Significance + effect size |
|---|---|---|---|
| **n** | **94** | **38** | |
| Age [a] | 23.07 (2.84) | 22.32 (2.18) | $F(1,130) = 2.185$, $p = .144$, $\eta_p^2 = 0.016$ |
| Female [b] | 47 (50.00%) | 23 (60.526%) | $X^2(1) = 1.204$, $p = .273$, $V = 0.095$ |
| Indigenous [b] | 4 (3.255%) | 2 (5.263%) | Fisher's Exact Test, $p = >.999$, $V = 0.022$ |
| Psychology student [b] | 51 (54.256%) | 23 (60.526%) | $X^2(2) = 3.160$, $p = .206$, $V = 0.155$ |
| Private university [b] | 12 (12.766%) | 14 (36.842%) | $X^2(1) = 9.917$, $p = .002$, $V = 0.274$ |
| SES [a] | 2.926 (1.184) | 3.737 (1.131) | $F(1,130) = 13.020$, $p < .001$, $\eta_p^2 = 0.091$ |

[a] = mean (+ standard deviation), [b] = count (+ percentage)

In addition, both SES score and university site were related to cognitive test performance. The bivariate correlations between cognitive test scores and the SES measure and the point biserial correlations of university are shown in Table 2. Several statistically significant correlations can be observed between either the SES measure or the university that the participants were recruited from. Overall, 6 of the 9 cognitive measures correlated significantly with either SES or university, the strongest being for language ability. The reasons for the associations between SES indices with both blood group and with cognitive performance are explored in the discussion. For the moment, it suffices to observe that these associations could have obfuscated any real relationship between blood group phenotype and cognitive performance. For that reason, they were controlled for in subsequent analyses.

Furthermore, although there was a balance of male and female participants from the public university, the recruits from the private university were predominantly female. This is a significant difference, $X^2(1) = 5.224$, $p = .022$, $V = 0.199$. That sex imbalance will largely be controlled by the aforementioned inclusion of university as a covariate in the ANCOVA calculations. However, the sex imbalance may still contribute to variance in cognitive test performance. To assess this, also included in Table 2 are the partial correlation values for the association between sex and cognitive performance. On most of the measures, there is no relationship between sex and performance, but there are two significant associations: for visuospatial processing and for executive functioning. In those later ANCOVA analyses on blood phenotype and cognitive performance, these are considered as potential covariates.

**Table 2.** Parametric correlation r values between the cognitive measures and factors related to socioeconomic status and biological sex

| Cognitive measure [a] | SES scale [b] | University [c] | Sex [d] |
|---|---|---|---|
| Shape recognition [e] | .052 | .152 | -.039 |
| Visuospatial processing [e] | .080 | -.055 | -.236** |
| Language [e] | .454*** | .544*** | .109 |
| Allocentric attention [e] | -.097 | -.222* | -.150 |
| Egocentric attention | .169 | .353*** | -.058 |
| Declarative memory | .226** | .178* | -.040 |
| Procedural memory | .181* | .121 | .057 |
| Advantageous decision making | .085 | .058 | .048 |
| Executive function | .333*** | .207* | -.203* |

[a] scored so that higher scores indicate better performance, [b] higher scores indicate higher SES, [c] point biserial correlation scored as public university = 1 and private university = 2, [d] partial point biserial correlation with male = 1 and female = 2, including University as a covariate, [e] RANKIT transformed data, *$p < .05$, **$p < .01$, ***$p < .001$

### 3.2 Main Analysis of Blood Type and Cognitive Ability

I then examined the associations between phenotypic blood group and cognitive test performance. These analyses employed ANOVA calculations with blood classification (O or non-O) as the independent variable and each cognitive measure individually entered as a dependent variable. Without covariates added, there were two significant differences: Type O were significantly worse on language, $F(1,130) = 11.976$, $p = .001$, $\eta_p^2 = 0.084$, and executive function, $F(1,129) = 4.970$, $p = .028$, $\eta_p^2 = 0.037$, as well as a trend for less balanced egocentric attention, $F(1,130) = 3.452$, $p = .065$, $\eta_p^2 = .026$. In contrast there was a trend for Type O being better at shape recognition, $F(1,130) = 3.594$, $p = .060$, $\eta_p^2 = 0.027$. However, these results are almost certainly confounded by the significantly higher frequency of the Type O phenotype at the public university, students from which were lower SES and had lower cognitive test scores in general. For this reason, the significant differences cannot be taken at face value. To obtain more precise effects, the next analyses were repeated with site of data collection and SES included as covariates.

Scores for the two phenotypic blood groups for the different measures of cognitive function are shown in Figure 1. There was only one statistical difference between groups. The Type O group performed significantly better on the object recognition task than the non-O group, $F(1,128) = 5.775$, $p = .018$, $\eta_p^2 = 0.043$. Although significant, this is qualitatively a 'small' effect size. It should also be noted that there was a trend for significance for the Type O group to perform worse than the non-O group on the measure of language function, $F(1,128) = 3.244$, $p = .074$, $\eta_p^2 = 0.025$. All the other significance tests were $p > .167$. I also considered the analysis of executive function scores with sex entered as a covariate, as it is one of the two cognitive scores related to sex in the correlations displayed in Table 2. This had only a small effect on the analysis, and it remained non-significant (changing from $p = .216$ to $p = .155$). I also entered sex as a covariate for

the ANCOVA on visuospatial processing scores (the other significant score in Table 2). The ANCOVA result remained non-significant, although the significance estimator dropped from $p = .229$ (without sex covaried) to $p = .150$ (with sex covaried).

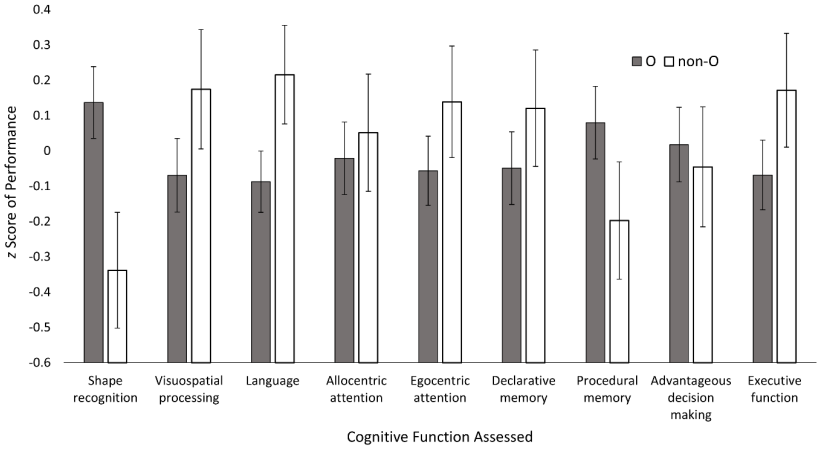


**Figure 1.** Comparison of performance on the different cognitive measures by the O and non-O blood groups.

**Note.** Mean z scores calculated on the full sample are shown to allow comparison of different cognitive measures on the same scale. The central tendencies shown are the estimated marginal means, adjusted for the covariates of SES score and university (private or public). Error bars are standard error of the mean values. Higher mean scores indicated better performance, or in the case of the two attentional measures, more balanced left-right search performance.

### 3.3 Secondary Analyses

Secondary analyses were used to explore the robustness of the main findings reported above. This was achieved by addressing the same hypotheses with different analytical methods. Returning to the only significant difference between phenotypic groups and cognitive performance, for visual shape recognition, this result was explored further. As reported above, if that analysis is performed without any covariates,

the significance in the combined sample from both sites is slightly diminished, at $p = .060$. Note however, that this analysis is biased by the overrepresentation of non-O group members in the generally better cognitively performing private university participants. If the analysis is repeated with university as a covariate, but without including the SES covariate, the advantage of the O group over the non-O group for shape recognition remains significant ($p = .013$).

Another way to examine this potential confound caused by differences in ratios of O to non-O in the two university sites is to analyze them separately. This avoids any artifacts introduced by covariance. When this is done, the same pattern of mean differences is observed, with the Type O group tending to perform better than the non-O group, and those differences are significant for the public university in Riobamba ($p = .050$), but not for the private university in Quito ($p = .113$). However, that non-significant difference is related to the much smaller sample sizes (12 O compared to 14 non-O participants), as the effect size is actually larger in the private university ($\eta_p^2 = 0.101$, 'medium' effect size) than it is in the public university ($\eta_p^2 = 0.037$, 'small' effect size). The mean raw test scores for these two samples (Riobamba and Quito) are shown in Figure 2, showing that the effect occurs in both samples, and that the private university sample from Quito performed better overall, when blood group is ignored.

That the broad result exists in two different samples, and either with or without covariates, suggests that this is probably not a false positive error, but reflects a real difference in visual shape recognition task performance between individuals with the Type O blood phenotype compared to those with other phenotypes.

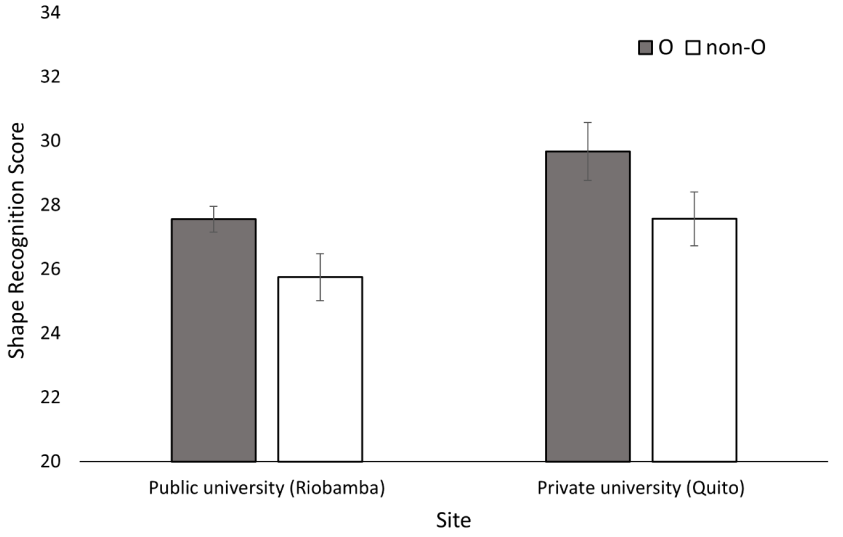


**Figure 2.** Comparison of performance on the shape recognition task by the O and non-O blood groups at the two different data collection sites.
**Note.** Shown are mean raw scores with errors bars indicating standard error of the mean.

Finally, I also further explored the observed language ability being worse in the blood Type O group compared to the non-O group, as that showed a trend for significance in the above ANCOVA analyses. When university sites are analyzed separately (still with SES as a covariate), the relative difference remains (O group worse), and the difference is significant in the private university sample, $F(1,23) = 6.969$, $p = .015$, $\eta_p^2 = 0.233$, but it is non-significant in the larger, public university sample, $F(1,103) = .830$, $p = .364$, $\eta_p^2 = 0.008$. These latter analyses suggest that the trend observed in the original analysis may not be replicable.

## 4. Discussion

The results revealed several significant associations between blood group,

SES, and cognitive functioning in human adults. First, Type O participants were from lower SES backgrounds than non-O participants. They were also more likely to be from one of the study sites than the other, which is probably related to SES. Second, lower SES was associated with worse cognitive function, including on measures of procedural and declarative memory, but with the strongest effects being on language skills and executive abilities. Third, blood phenotype was associated with cognitive performance but in a much more limited way. The group with the O blood phenotype performed a shape recognition task significantly better than the group with non-O blood phenotypes. There were no blood group associations with any of the other cognitive measures.

Focusing on the first point, the significant association of Type O blood phenotype with lower SES, previous research has not usually observed such associations. In this case, the likely explanation is related to the high level of Type O blood in Indigenous American populations compared to those from Ecuadorian Mestizos. As previously noted, it is thought that almost all pre-Columbian peoples in the Americas were of Type O blood. In contrast the modern Ecuadorians with European heritage (Mestizos) are more likely to have the A and B alleles, and also tend to occupy higher SES strata for historical reasons related to the race-based distribution of power and wealth introduced in colonial times (Hall & Patrinos, 2012). A peripheral finding of the current research therefore is an SES-based cline in ABO blood group frequencies, which may be specific to the Americas.

On the second point, I observed several associations between SES and cognitive test scores. The strongest effects, in order, were for language, executive function, declarative memory, and procedural memory. For the first three cognitive functions this is a fairly typical finding (see e.g., Farah, 2017) although it may be notable as a confirmation of the basic finding from a non-WEIRD country. The majority of research on SES effects on cognitive function are from the so-called WEIRD countries, i.e., Western,

Educated, Industrialized, Rich and Democratic countries (Henrich et al., 2010). In the current research I observed a positive association of SES with procedural memory ability. This is in contrast to previous research which has suggested the opposite effect, i.e., better procedural learning related to lower SES (Dang et al., 2016).

The third point was of central interest in the current research, the association between blood group phenotype and cognitive function. The findings for these analyses were far more focused, and the only association observed was for better shape recognition performance, with the Type O blood phenotype, compared to other phenotypes. Due to the other, non-cognitive, observed associations, it was necessary to covary for the effects of confounding variables. SES and recruitment site were included as covariates in the main analyses because both were related to blood group and cognitive test performance. However, it should be noted that without the inclusion of covariates there would have been more significant between-group differences, caused by the confounding effects of SES and research site. Covariance was used to here to eliminate false positives.

With confounding factors controlled for, shape recognition task performance was identified as the only measure to show a difference based on blood phenotype. However, this result seems to remain even without the covariance for SES, and the effect is apparent in the two separate samples (see Figure 2), suggesting that it is not a type I error caused by multiple testing or an artefact of statistical corrections. Further, most past research has shown a clinical-cognitive or clinical-neurological advantage of O blood over non-O blood types. The current significant result (and despite the use of two-tailed analyses) is in the same direction and generally accords with the extant literature (Alexander et al., 2014; Li et al., 2017; Pisk et al., 2019; Sabino Ade et al., 2014; Wiggins et al., 2009). The current finding implies an advantage associated with type O blood, compared to non-O blood types, in pre-categorial visual shape recognition processes, of the type associated

with early stages in the ventral visual pathway involving occipital and temporal cortex. No associations were found with spatial vision linked to the posterior parietal cortex, language or spatial attention linked to the perisylvian cortices, memory linked to the medial temporal lobe and basal ganglia, nor advantageous decision making, or executive functions linked to the prefrontal cortex.

Although tentative, the current results contribute to the growing literature that suggests some neurological and cognitive benefit associated with having the O blood phenotype, compared to the non-O phenotype. However, this is not to be taken to imply that any individuals are more able based on their genetic inheritance. The current findings are based upon test performance, which can be influenced by multiple factors, beyond ability. Although we compared groups identified by their ABO phenotype, many other factors likely varied between the groups for sociocultural reasons, such as individual differences in basic cognitive processes or styles. Such variation would influence performance in various tasks, including those not specifically related to visual cognition. Each of the cognitive tasks employed in the current study would have involved multiple such factors. It may be that the association with ABO blood group phenotype is driven by inter-individual variation in the finer-grained cognitive processes or styles that particularly influence performance on the object recognition task. This could occur because the object recognition task had a different format to the other tests used in the assessment battery. Similarly, the phenotypic groups likely varied in other ways, such as personality. Given that the object recognition task had a different format to the other tasks in the cognitive battery, it may have been differentially sensitive to such individual difference factors. For example, the groups may have varied in how motivated or engaged they were with the task, or with strategies applied. Such variation could occur for sociocultural, not biological reasons. Further research may refute or confirm whether the reported association is acting directly through visual cognitive

processes, or more general cognitive or dispositional factors.

Cognitive reserve is a clinical phenomenon in which higher cognitive ability appears to have a protective effect against the development of several neurological illnesses (Stern, 2009). In addition to the studies indicating lower risk of ischemic stroke in type O individuals, the current results suggest a possible role for the same phenotype in providing cognitive reserve, which could further protect against severity of cognitive symptoms following neurological illness. Although slightly better shape recognition may only provide a small amount of reserve, the current observation simply reveals that cognitive test performance is related to the ABO blood group system. Only a small number of abilities were assessed in this exploratory study. It is quite possible that further studies will identify other strengths and weaknesses in cognitive performance linked to blood group.

Nevertheless, from the current findings, an important question arises – how could blood type be associated with visual shape recognition? There is no clear answer to this, and the suggestions given here should be considered as highly speculative. One possibility is that type O blood group has previously been associated with larger volumes in parts of the temporal lobes bilaterally (De Marco & Venneri, 2015). The shape recognition test used here is one that has been shown to be sensitive to functioning of an area on the lateral occipito-temporal cortex, the LOC (Cavina-Pratesi et al., 2010). On the one hand, this may seem like a tenuous association, given that the areas identified as larger in people with Type O blood were anterior temporal lobe, not posterior, stranding the occipital and temporal lobes as the LOC does.

On the other hand, performance in the shape recognition task clearly would have involved more than just the processing in the LOC. Object-based working memory processes for comparing shapes presented together would likely be an important factor. The O type associated areas identified in the MRI study on the anterior inferior temporal lobes are very similar to

regions associated specifically with object-based visual working memory, as opposed to visuospatial working memory (Nee & D'Esposito, 2015). It is worth noting that the task used in this research aimed to minimize spatial processing to focus on object-based processing.

However, the result of better performance linked to type O blood was qualitatively small, and may have only a marginal ecological effect. Furthermore, it could well have been caused by lower-level visual processing differences associated with blood group. The antigens which define the ABO blood groups are not only found on red blood cells, but have also been detected on sensory nerves in the dorsal root ganglions in humans, and their expression on those nerves matches the ABO blood group (Mollicone et al., 1986). Furthermore, ABO antigens are also expressed in rodent taste buds (Smith et al., 1994) olfactory neurons (St John et al., 2006), and cochlear sensory cells (Gil-Loyzaga, 1997). Although there are currently no reports of these antigens being associated with retinal cells or the optic nerve, the studies raise the possibility that blood group phenotypes could be related to sensory processes and could potentially influence ostensibly higher visual processes such as object recognition. Furthermore, the main result reported in this study could equally be a consequence of intermediate processes between the sensory neurons and cortical processes, including related processes such as eye movement control. Nevertheless, to reiterate, these are highly speculative suggestions and should be considered cautiously. Finally, as the non-O phenotype likely indicates gene admixture resulting from colonization since the 16th century, it may be simply a correlate of other genetic variation introduced at the same time. In this scenario, the physiological differences caused by the alleles specifying O or non-O phenotypes may have no direct effect on cognition.

This study used a cross-sectional design to examine cognitive performance across blood types. The direction of the result is consistent with previous research that has compared people with the O phenotype

with all others in the ABO group, i.e., people who have alleles for either A or B or antigens. This is the simplest analysis, but it ignores any possible differences between people with the various A and B combinations. In the current research, although there were many participants with Type O blood ($n$ = 94), and a reasonable number with Type A ($n$ = 25), there were few with Type B ($n$ = 10) or Type AB ($n$ = 3). This precludes the finer-grained analysis. This can be considered a weakness of the research, which was caused by the sample size. In fact, as self-report of blood group was used for group allocation, rather than laboratory tests of blood group alleles, the data cannot distinguish individuals with the AO phenotype from those that are AA or those that are BO from BB. Genetic analyses could provide more detailed knowledge of actual ABO blood group genotypes and would also be somewhat more reliable than self-report.

A further issue is that the data were collected in the Sierra region of Ecuador, an area at relatively high altitude. This may limit the generalizability of the results. As such, further research could confirm whether the same association between ABO blood group variations and cognitive test performance is found in other populations and geographical regions. I also acknowledge that as individuals participated for grade credits, there may be implications for their determination when completing cognitive tests. However, research tends to indicate that there is no difference in performance for college-student participants who are reimbursed with cash or course credits (e.g., Luccasen III & Thomas, 2014). Nevertheless, these limitations of the current research are acknowledged.

## 5. Conclusions

Based on our results from Ecuador, I suggest that there is sufficient evidence to argue that basic visual shape processing task performance is linked to ABO blood group phenotypes, with the O type linked to better

performance than the other phenotypes. This represents an interesting biomarker of neurocognitive function, which could be used to enhance understanding of visual processing in the brain and to understand cognitive processes as individual differences linked to physiology.

**Acknowledgement** I would like to thank Isabela Lara for assistance with construction of the tests and training researchers, Dr. Patricia Bravo for organizing data collection in Riobamba, Emilia Montano for data collection in Quito, and Dr. Helen Johnson for language advice and proofreading.

**Funding** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Declarations

**Ethics Approval** Ethical approval to conduct this research was granted by the Bioethics Committee at Universidad San Francisco de Quito, Ecuador.

**Consent to Participate and Consent for Publication** Cognitive testing and other data collection was performed with informed signed consent from all participants for participation and publication.

**Conflict of Interest** The author has no conflict of interest to declare.

## References

Alexander, K. S., Zakai, N. A., Gillett, S., McClure, L. A., Wadley, V., et al. (2014). ABO blood type, factor VIII, and incident cognitive impairment in the REGARDS cohort. *Neurology, 83*(14), 1271-1276. https://doi.org/10.1212/WNL.0000000000000844

Ashton, G. C. (1986). Blood polymorphisms and cognitive abilities. *Behavior Genetics, 16*(5), 517-529. https://doi.org/10.1007/bf01066338

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50*(1-3), 7-15. https://doi.org/10.1016/0010-0277(94)90018-3

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science, 275*(5304), 1293-1295. https://doi.org/10.1126/science.275.5304.1293

Benton, A. L., Sivan, A. B., Hamsher, K., Varney, N. R., & Spreen, O. (1994). Three-dimensional block construction. In *Contributions to neuropsychological* assessment: a clinical manual (2nd ed., pp. 115-136). Oxford University Press.

Bider-Canfield, Z., & Cotterchio, M. (2014). Self-reported ABO blood type compared with DNA-derived blood group. *Epidemiology*, 25(6), 936-937. https://doi.org/10.1097/EDE.0000000000000156

Catani, M., Jones, D. K., & ffytche, D. H. (2005). Perisylvian language networks of the human brain. *Annals of Neurology, 57*(1), 8-16. https://doi.org/10.1002/ana.20319

Cavina-Pratesi, C., Kentridge, R. W., Heywood, C. A., & Milner, A. D. (2010). Separate processing of texture and form in the ventral stream: evidence from fMRI and visual agnosia. *Cerebral Cortex, 20*(2), 433-446. https://doi.org/10.1093/cercor/bhp111

Chen, Z., Yang, S. H., Xu, H., & Li, J. J. (2016). ABO blood group system and the coronary artery disease: an updated systematic review and meta-analysis. *Scientific Reports, 6*, 23250. https://doi.org/10.1038/srep23250

Coucha, M., Abdelsaid, M., Ward, R., Abdul, Y., & Ergul, A. (2018). Impact of metabolic diseases on cerebral circulation: structural and functional consequences. *Comprehensive Physiology, 8*(2), 773-799. https://doi.org/10.1002/cphy.c170019

Dang, J., Xiao, S., Zhang, T., Liu, Y., Jiang, B., et al. (2016). When the poor excel: Poverty facilitates procedural learning. *Scandinavian Journal of Psychology, 57*(4), 288-291. https://doi.org/10.1111/sjop.12292

De Marco, M., & Venneri, A. (2015). 'O' blood type is associated with larger grey-matter volumes in the cerebellum. *Brain Research Bulletin, 116*, 1-6. https://doi.org/10.1016/j.brainresbull.2015.05.005

del Zoppo, G. J. (2010). The neurovascular unit in the setting of stroke. *Journal of Internal Medicine, 267*(2), 156-171. https://doi.org/10.1111/j.1365-2796.2009.02199.x

Delaney, M., Harris, S., Haile, A., Johnsen, J., Teramura, G., et al. (2015). Red blood cell antigen genotype analysis for 9087 Asian, Asian American, and Native American blood donors. *Transfusion, 55*(10), 2369-2375. https://doi.org/10.1111/trf.13163

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System.* Psychological Corporation.

Etemadi, A., Kamangar, F., Islami, F., Poustchi, H., Pourshams, A., et al. (2015). Mortality and cancer in relation to ABO blood group phenotypes in the Golestan Cohort Study. *BMC Medicine, 13*, 8. https://doi.org/10.1186/s12916-014-0237-8

Farah, M. J. (2017). The neuroscience of socioeconomic status: correlates, causes, and consequences. *Neuron, 96*(1), 56-71. https://doi.org/10.1016/j.neuron.2017.08.034

Gibson, J. B., Harrison, G. A., Clarke, V. A., & Hiorns, R. W. (1973). IQ and ABO blood groups. *Nature, 246*(5434), 498-500. https://doi.org/10.1038/246498a0

Gil-Loyzaga, P. (1997). Histochemistry of glycoconjugates of the auditory receptor-functional implications. *Progress in Histochemistry and Cytochemistry, 32*(1), 1-80. https://doi.org/10.1016/s0079-6336(97)80008-3

Glascher, J., Adolphs, R., Damasio, H., Bechara, A., Rudrauf, D., et al. (2012). Lesion mapping of cognitive control and value-based decision making in the prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America, 109*(36), 14681-14686. https://doi.org/10.1073/pnas.1206608109

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15*(1), 20-25. https://doi.org/10.1016/0166-2236(92)90344-8

Hall, G. H., & Patrinos, H. A. (2012). Introduction. In G. H. Hall & H. A. Patrinos (Eds.), *Indigenous peoples, poverty, and development.* Cambridge University Press. https://doi.org/10.1017/CBO9781139105729.001

Halverson, M. S., & Bolnick, D. A. (2008). An ancient DNA test of a founder effect in Native American ABO blood group frequencies. *American Journal of Physical Anthropology, 137*(3), 342-347. https://doi.org/10.1002/ajpa.20887

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and Brain Sciences, 33*(2-3), 61-83. https://doi.org/10.1017/S0140525X0999152X

Instituto Nacional de Estadística y Censos. (2011). Encuesta de Estratificación del Nivel Socioeconómico NSE 2011. https://www.ecuadorencifras.gob.ec//documentos/web-inec/Estadisticas_Sociales/Encuesta_Estratificacion_Nivel_Socioeconomico/111220_NSE_Presentacion.pdf

Ito, H., Matsuo, K., Saito, T., Hirose, K., Inoue, M., et al. (2001). Valid responses to ABO blood type question in self-reporting questionnaire. *Asian Pacific Journal of Cancer Prevention, 2*(4), 315-317. https://www.ncbi.nlm.nih.gov/pubmed/12718625

Jenkins, P. V., & O'Donnell, J. S. (2006). ABO blood group determines plasma von Willebrand factor levels: a biologic function after all? *Transfusion, 46*(10), 1836-1844. https://doi.org/10.1111/j.1537-2995.2006.00975.x

Karnath, H. O. (2009). A right perisylvian neural network for human spatial orienting. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (4th ed., pp. 259-268). MIT Press.

Kelleher, C., Cooper, J., & Sadlier, D. (1990). ABO blood group and social class: a prospective study in a regional blood bank. *Journal of Epidemiology and Community Health, 44*(1), 59-61. https://doi.org/10.1136/jech.44.1.59

Kilroy, E., Liu, C. Y., Yan, L., Kim, Y. C., Dapretto, M., et al. (2011). Relationships between cerebral blood flow and IQ in typically developing children and adolescents. *Journal of Cognitive Science, 12*(2), 151-170.

Kim, H. Y. (2013). Statistical notes for clinical researchers: assessing normal distribution (2) using skewness and kurtosis. *Restorative Dentistry and Endodontics, 38*(1), 52-54. https://doi.org/10.5395/rde.2013.38.1.52

Kincses, T. Z., Antal, A., Nitsche, M. A., Bartfai, O., & Paulus, W. (2004). Facilitation of probabilistic classification learning by transcranial direct current stimulation of the prefrontal cortex in the human. *Neuropsychologia, 42*(1), 113-117. https://doi.org/10.1016/s0028-3932(03)00124-6

Knowlton, B. J., Mangels, J. A., & Squire, L. R. (1996). A neostriatal habit learning system in humans. *Science, 273*(5280), 1399-1402. https://doi.org/10.1126/science.273.5280.1399

Langer, N., Pedroni, A., Gianotti, L. R., Hanggi, J., Knoch, D., et al. (2012). Functional brain network efficiency predicts intelligence. *Human Brain Mapping, 33*(6), 1393-1406. https://doi.org/10.1002/hbm.21297

Li, J., Zhou, J., Wan, Y., Liu, L., & Ou, C. (2017). Association between ABO blood type and postoperative cognitive dysfunction in elderly patients undergoing

unilateral total hip arthroplasty surgery in China. *Medical Science Monitor, 23*, 2584-2589. https://doi.org/10.12659/msm.901736

Llop, E., & Rothhammer, F. (1988). A note on the presence of blood groups A and B in pre-Columbian South America. *American Journal of Physical Anthropology, 75*(1), 107-111. https://doi.org/10.1002/ajpa.1330750112

Lodish, H., Berk, A., Kaiser, C. A., Krieger, M., Scott, S. P., et al. (2008). *Molecular cell biology* (6th ed.). W.H. Freeman and Company.

Luccasen III, R. A., & Thomas, M. K. (2014). Monetary incentives versus class credit: Evidence from a large classroom trust experiment. *123, 2,* 232-235. https://doi.org/10.1016/j.econlet.2014.02.012

Mollicone, R., Davies, D. R., Evans, B., Dalix, A. M., & Oriol, R. (1986). Cellular expression and genetic control of ABH antigens in primary sensory neurons of marmoset, baboon and man. *Journal of Neuroimmunology, 10*(3), 255-269. https://doi.org/10.1016/0165-5728(86)90106-2

Nee, D. E., & D'Esposito, M. (2015). Working memory. In A. W. Toga (Ed.), *Brain mapping: an encyclopedic reference* (Vol. 2). Academic Press. https://doi.org/10.1016/B978-0-12-397025-1.00050-6

Ota, H., Fujii, T., Suzuki, K., Fukatsu, R., & Yamadori, A. (2001). Dissociation of body-centered and stimulus-centered representations in unilateral neglect. *Neurology, 57*(11), 2064-2069. https://doi.org/10.1212/wnl.57.11.2064

Ouerchefani, R., Ouerchefani, N., Allain, P., Ben Rejeb, M. R., & Le Gall, D. (2019). Relationships between executive function, working memory, and decision-making on the Iowa Gambling Task: Evidence from ventromedial patients, dorsolateral patients, and normal subjects. *Journal of Neuropsychology, 13*(3), 432-461. https://doi.org/10.1111/jnp.12156

Pike, M. M., Larson, N. B., Wassel, C. L., Cohoon, K. P., Tsai, M. Y., et al. (2017). ABO blood group is associated with peripheral arterial disease in African Americans: The Multi-Ethnic Study of Atherosclerosis (MESA). *Thrombosis Research, 153*, 1-6. https://doi.org/10.1016/j.thromres.2017.02.018

Pisk, S. V., Vuk, T., Ivezic, E., Jukic, I., Bingulac-Popovic, J., et al. (2019). ABO blood groups and psychiatric disorders: a Croatian study. *Blood Transfussion, 17*(1), 66-71. https://doi.org/10.2450/2018.0266-17

Pluck, G., Bravo Mancero, P., Maldonado Gavilanez, C. E., Urquizo Alcivar, A. M., Ortiz Encalada, P. A., et al. (2019). Modulation of striatum based non-declarative and medial temporal lobe based declarative memory predicts

academic achievement at university level. *Trends in Neuroscience and Education, 14*, 1-10. https://doi.org/10.1016/j.tine.2018.11.002

Pluck, G., Córdova, M. A., Bock, C., Chalen, I., & Trueba, A. F. (2021). Socioeconomic status, executive functions, and theory of mind ability in adolescents: Relationships with language ability and cortisol. *British Journal of Developmental Psychology, 39*(1), 19-38. https://doi.org/10.1111/bjdp.12354

Rahm, C., Liberg, B., Wiberg-Kristoffersen, M., Aspelin, P., & Msghina, M. (2013). Rostro-caudal and dorso-ventral gradients in medial and lateral prefrontal cortex during cognitive control of affective and cognitive interference. *Scandinavian Journal of Psychology, 54*(2), 66-71. https://doi.org/10.1111/sjop.12023

Richardson, J. T. E. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review, 6*(2), 135-147. https://doi.org/10.1016/j.edurev.2010.12.001

Rolfe, D. F., & Brown, G. C. (1997). Cellular energy utilization and molecular origin of standard metabolic rate in mammals. *Physiological Reviews, 77*(3), 731-758. https://doi.org/10.1152/physrev.1997.77.3.731

Sabino Ade, P., Ribeiro, D. D., Domingheti, C. P., Rios, D. R., Dusse, L. M., et al. (2014). ABO blood group polymorphisms and risk for ischemic stroke and peripheral arterial disease. *Molecular Biology Reports, 41*(3), 1771-1777. https://doi.org/10.1007/s11033-014-3026-8

Sanchez-Boiso, A., Penaloza-Espinosa, R. I., Castro-Sierra, E., Cerda-Flores, R. M., Buentello-Malo, L., et al. (2011). Genetic structure of three Native Mexican communities based on mtDNA haplogroups, and ABO and Rh blood group systems. *Revista De Investigacion Clinica, 63*(6), 614-620. https://www.ncbi.nlm.nih.gov/pubmed/23650674

Schaeffer, S., & Iadecola, C. (2021). Revisiting the neurovascular unit. *Nature Neuroscience, 24*(9), 1198-1209. https://doi.org/10.1038/s41593-021-00904-7

Smith, D. V., Klevitsky, R., Akeson, R. A., & Shipley, M. T. (1994). Taste bud expression of human blood group antigens. *Journal of Comparative Neurology, 343*(1), 130-142. https://doi.org/10.1002/cne.903430110

Soloman, S. R., & Sawilowsky, S. S. (2009). Impact of rank-based normalizing transformations on the accuracy of test scores. *Journal of Modern Applied Statistical Methods, 8*(2), 448-462. https://doi.org/10.22237/jmasm/1257034080

Spiel, A. O., Gilbert, J. C., & Jilma, B. (2008). von Willebrand factor in

cardiovascular disease: focus on acute coronary syndromes. *Circulation, 117*(11), 1449-1459. https://doi.org/10.1161/CIRCULATIONAHA.107.722827

St John, J. A., Claxton, C., Robinson, M. W., Yamamoto, F., Domino, S. E., et al. (2006). Genetic manipulation of blood group carbohydrates alters development and pathfinding of primary sensory axons of the olfactory systems. *Developmental Biology, 298*(2), 470-484. https://doi.org/10.1016/j.ydbio.2006.06.052

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia, 47*(10), 2015-2028. https://doi.org/10.1016/j.neuropsychologia.2009.03.004

Sumiyoshi, A., Keeley, R. J., & Lu, H. (2019). Physiological considerations of functional magnetic resonance imaging in animal models. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 4*(6), 522-532. https://doi.org/10.1016/j.bpsc.2018.08.002

Weintraub, S., Mesulam, M. M., Wieneke, C., Rademaker, A., Rogalski, E. J., et al. (2009). The Northwestern Anagram Test: measuring sentence production in primary progressive aphasia. *American Journal of Alzheimer's Disease and Other Dementias, 24*(5), 408-416. https://doi.org/10.1177/1533317509343104

Wiggins, K. L., Smith, N. L., Glazer, N. L., Rosendaal, F. R., Heckbert, S. R., et al. (2009). ABO genotype and risk of thrombotic events and hemorrhagic stroke. *Journal of Thrombosis and Haemostasis, 7*(2), 263-269. https://doi.org/10.1111/j.1538-7836.2008.03243.x