Visual Perceptual Ability and Academic Achievement in Undergraduate Engineering

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***Abstract*— Cognitive and neurosciences provide new ways to advance the scholarship of learning and teaching. One such application is identification of the cognitive processes that contribute to academic achievement. Intelligence testing has been shown to be of limited use in higher education, and so there is a need to identify other cognitive and neurobehavioral factors that may be important. One possibility, in the context of STEM education, is visuospatial ability, as this has been linked to achievement in several technical, or things-based courses. In the current study, 60 industrial engineering students and 60 social sciences students were assessed on a task of visual size judgement, and the ability of performance to predict grade point average (GPA) scores was estimated. It was found that size judgement was significantly and positively correlated with GPA within the engineering group, but not in the social sciences group. Furthermore, the results could not be explained by demographic factors such as sex or age. It is concluded that visual perceptual ability, specifically size judgement, may be a useful predictor of academic achievement, and may thus help to partly explain why some engineering students excel, and others do not. Furthermore, potential for training of visuospatial skills to enhance attainment in engineering training is discussed.**

Keywords—cognitive ability, visuospatial ability, academic achievement, higher education, STEM, engineering, neuroeducation

I. Introduction

There is currently a growing awareness of the importance of interdisciplinary links between the scholarship or learning and teaching, and cognitive and brain sciences. Where these successfully come together, the field is often described as educational neuroscience. This collaboration helps to advance pedagogy by providing guidance for evidence-based practice.

One of the important issues in STEM education, and education in general, is understanding why some students achieve more than others. Combining data from thousands of pedagogical studies, it has been estimated that the single largest factor that determines success of learning in higher education is what the student brings to the situation, such as their personality, past leaning, and cognitive ability. This explains about 50% of the variation in higher education grades, in contrast, only about 20-25% is explicable by variation in teaching practices and teacher abilities [1].

An important student-based factor is almost certainly the ways in which individual students process information, that is, their cognitive abilities such as attention, memory, and problem-solving capacity. This is of course a property of the functioning of the nervous system, as such, the existing knowledge on cognitive processes and the brain should be directly applicable to education.

However, much research in this field has been focused on a largely discredited theory of learning styles. That approach has been extensively researched but many well-known cognitive and brain scientists believe that it is an approach lacking empirical support and should be abandoned [2].

The concept of general intelligence has substantially more support from cognitive and brain sciences, and indeed has developed, since its inception at the beginning of the 20th century, with a focus on educational achievement. However, intelligence has proven itself to be a consistent, though only modest predictor of achievement in higher education. Overall, only about 4% of variation in higher education grades can be explained by intelligence test scores, based on a mean r value of 0.2 [3].

Consequently, the actual cognitive processes which ultimately support academic achievement in higher education are largely unknown. This is unfortunate, as there is currently much greater appreciation that cognitive and brain sciences can enhance pedagogical practice, but on one of the biggest issues, there are no clear answers. One suggestion has been that cognitive abilities that are relatively independent of intelligence, such as response inhibition, may be particularly important in prediction higher education achievement in general [4-5]. However, such broad effects are likely to be of limited utility.

This is because of the varied contexts of higher education. In particularly, it seems likely that the cognitive abilities that support advancement in STEM fields are different to those that support advancement in other fields, such as humanities and arts. In support of this, a recent study has shown that while psychological health, but not intelligence, is predictive of grade point average (GPA) of social science undergraduates, the reverse pattern is found for engineering students [5].

For students in mathematically-intense STEM programs at university (e.g., mechanical engineering, math, physics) working memory, the ability to store and process information over very short periods has recently been shown to be a good predictor of grades [6]. For students studying design and computer graphics, various aspects of visuospatial cognitive processing are important predictors of success [7]. Similarly, spatial cognitive skills have been found to be associated with various measures of academic performance (e.g., math and science SAT scores) among freshman engineering students [8]. Furthermore, educational interventions with engineering students to improve their visuospatial ability have been shown to lead to improved GPA [9].

However, some caution is needed when interpreting such results. An important consideration is that engineering courses frequently have an overrepresentation of male students. This is relevant because some visuospatial tasks are performed differently by male and female participants, and this also has an age dimension: the male advantage of spatial tasks improves with age through adolescence [10]. These sex and age effects could potentially distort the association between

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visuospatial processing and achievement of engineering students.

Nevertheless, there is a reasonable amount of evidence that visuospatial skills are important in several aspects of engineering. Although, admittedly, engineering is a very wide field with many different skills required. For example, industrial engineering involves, among other skills, design and visualization of processes in manufacturing, which are likely quite different to many other branches, such as software engineering, which involves a great of logical and verbal processing. Similarly, the concept of 'visuospatial skill' encompasses a wide range of abilities including object recognition, mental rotation, envisaging 3-D models, recognition of spatial configurations etc.

Of particular current interest, it has been shown that there is domain-general object recognition system in the human brain. This means that people who are good at recognizing similarities and differences between objects, can do so across different tasks and different domains (e.g., vision, audition) [11]. Importantly, this object recognition system is independent of the domain-general fluid intelligence processes, collectively known as the multiple-demand system, which is thought to organize problem solving in novel situations. It is the latter cognitive system that produces 'intelligence' [12] as it is measured by psychologists and educationalists, and has been widely applied for screening college admissions.

The domain-general object recognition system thus presents an alternative cognitive system to that traditionally associated with intelligence, which could potentially explain some of the variation in academic achievement associated with success in higher education. If so, this may particularly involve 'things-based' vocations as opposed to 'people-based' vocations, which has been shown to be an important dimension that people vary in regarding to their training and occupational choices. Engineering is considered to be a polar example of a things-based college major [13].

It is hypothesized that success in industrial engineering education at university will be partly dependent on skill in spatial and object processing. In the current research, the hypothesis is evaluated in terms of one specific skill, that is, recognition of differences in visual size between identical form objects. To this end, we examined the performance of a group of industrial engineering undergraduate students on a size judgment task with abstract designs, and calculated how predictive performance is of course GPA.

As a comparison, we also included a group of social science students with psychology as a major, as this represents the opposite pole, i.e., a 'people-based' subject [13]. This allows for testing the specificity of any observed association (i.e., does it appear to be specific to the industrial engineering students, or does it likely predict performance of students in diverse majors, including social science students).

In addition, potential confounds of sex and age were also considered in the analyses.

II. Method

A. Research Design

The research reported here used a correlational, cross-sectional method, but including a prospective follow up of GPA scores to allow predictions to be made. Two separate samples of undergraduate students were recruited and assessed for their visuospatial ability, a sample of industrial engineering students studying in their second year of an undergraduate degree, and a sample of psychology students, also in the second year of their degree. GPA was calculated for all research participants to be compared with performance on the visuospatial task.

B. Participants

A sample of 60 industrial engineering students was recruited. They had a median age of 22.8 years (range = 20.4–36.8) and 14 (23%) were female. A sample of 60 psychology students at the same university was also recruited, their median age was 22.1 years (range = 20.1–30.3) and 47 (78%) were female. All participants were screened for sensory impairments that might affect performance and all had normal vision, or vision that was corrected (for example, with spectacles).

C. Measures

A set of 27 different designs were produced, all black on a white background. Novel designs were used as these would not be familiar to the participants and would prevent interference from past associations. The designs were deliberately complex, this impedes simple matching of size by impression of surface area, as each design had multiple strokes. Each of the 27 different designs was shown on a 10-inch screen tablet computer, with two versions of the design, one slightly larger than the other. An example is given in Fig. 1. These were shown in a vertical alignment to avoid the slight left-right attentional biases that are known to affect performance on some visual cognition tasks. The area of the two shapes (width x height) was never the same. The difference in total area ranged from 12% to 16% difference.

On average the square area of each shape on the screen was 1,425 mm^2. On approximately half of the 27 trials the top version was larger, and on the other half the lower version was larger (this was randomized and unpredictable by the participant).

The task for the participant was to say which was the larger of the two. Each trial began with a blank screen containing only a fixation cross in the center of the screen, shown for one second. This was followed immediately by the designs, which were shown for 1.5 seconds. Then a completely blank screen was shown for 3 seconds, during which the participant could give their answer. The response was recorded by the experimenter. This continued until all 27 trials were completed.

In the sample trial shown in Fig. 1 the correct response would have been to say 'upper', earning one point for a correct response. The total possible score on this test was 27 points. The GPA for each student was extracted from the university systems, and was taken approximately six months after research participation so that it included all grades from five completed semesters of study. In this university, GPA is scored from 1-10, with higher scores indicating better performance. As the sum of five semesters was used, the potential score range was from 0-50.

D. Procedure

All participants were assessed individually in interviews involving one participant and two experimenters. These interviews were conducted in a quiet, dimly lit, private room on the university campus.

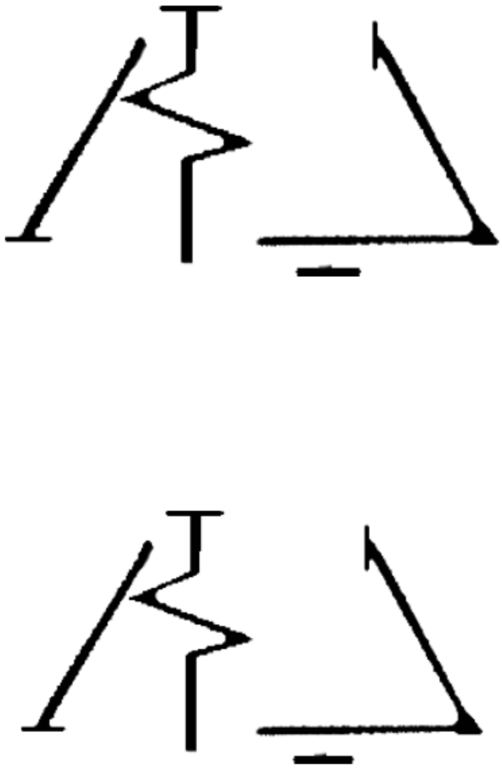

Fig. 1. Example of a single trial from the size judgment task.

All data was collected within a single university semester. Other cognitive data was collected which has been published in a separate study. However, the data presented here has not been previously published. The total interview for each participant took approximately 100 minutes, and all participants received grade credits for participation. When GPA data become available later, the full data set was processed and analyzed with SPSS.

E. Research ethics

All participants gave written, informed consent to participate in this study. The research protocol was approved by a recognized Institutional Review Board. In addition, all procedures were consistent with major ethical guidelines, including those of the American Psychological Association.

III. Results

A. Data distributions

The total score on the size judgement task was calculated for each participant individually. Analysis of the distributions of the total scores revealed that in the engineering sample, one participant scored more than three standard deviations below the sample mean. Similarly, one participant in the psychology sample scored more than three standard deviations below the sample mean. That criterion is frequently used to identify outlying data points, and so both cases were excluded from further analysis, as they likely indicated participants who had not followed task instructions.

Of the remaining samples, data distributions were assessed with Kolmogorov-Smirnov tests. For the size judgment task, scores in both samples deviated significantly from normal distributions. For this reason, non-parametric analyses were used for further analyses. The median score of the Engineering sample was 25, and in the Psychology sample it was 26. That small difference was not significant (Mann-Whitney U Test, $p = .33$).

B. Demographic factors

There were no associations between demographic variables and size judgement task performance: For either age or sex, analyzed as either separate groups by major, or as a combined sample (all age ps > .41; all sex ps > .11).

However, as anticipated, demographic factors were related to GPA scores. Female participants had a total GPA across all five semesters of 42.1 (SD = 3.3), which is higher than for the male participants who had a mean of 38.6 (SD = 3.3), a significant difference, $t(116) = -5.84$, $p < .01$, $d = 1.08$. However, this was mainly explained by overall higher GPA of courses ran in the psychology faculty (mean = 43.2, SD = 2.1), compared to those in the engineering faculty (mean = 37.6, SD = 2.7), also a significant difference, $t(116) = 12.61$, $p < .01$, $d = 2.3$.

When sex differences were analyzed separately by faculty, there were no significant differences for GPA between male and female students, though the difference was approaching significance in the psychology sample, $p = .06$. Age was not correlated with size judgement performance in the full sample ($p = .61$), but it was approaching significance in its correlation with GPA ($p = .05$). The only significant association was between age and GPA in the psychologist student sample, $r = -.28$ $p = .03$), suggesting that younger students achieved higher grades.

C. Perceptual ability and GPA

The main correlational analysis of size judgement task performance and GPA is shown in Table 1. This displays the simple zero order (Spearman) correlation coefficients for the association between GPA and size judgement performance. The only measure that was statistically significant was a positive correlation for the engineering students. This relationship is also shown graphicly in Fig. 2, which gives the scatter plots, with regression lines fitted. In that figure it can be seen that the relationship between size judgement performance and GPA only existed in the engineering student sample.

To assess the possible confounding of sex and age factors, partial correlations were also performed, in which those demographic measures were held constant. This is also shown in Table 1. To do this it was necessary to use ranked variables within the normal partial correlation procedure, due to non-normality data distributions. The partial correlations confirmed that the association between GPA of engineering students and their size judgement ability was not caused by variation of demographic factors such as age or sex within the samples.

TABLE I. CORRELATIONS BETWEEN GPA AND SIZE JUDGEMENT TASK PEROMANCE

Sample	**Correlation type**	
	Zero order r	***Partial r***
Engineering	.25*	.26*
Psychology	-.21	-.18
All students	.11	.14

* $p < .05$ (one-tailed)

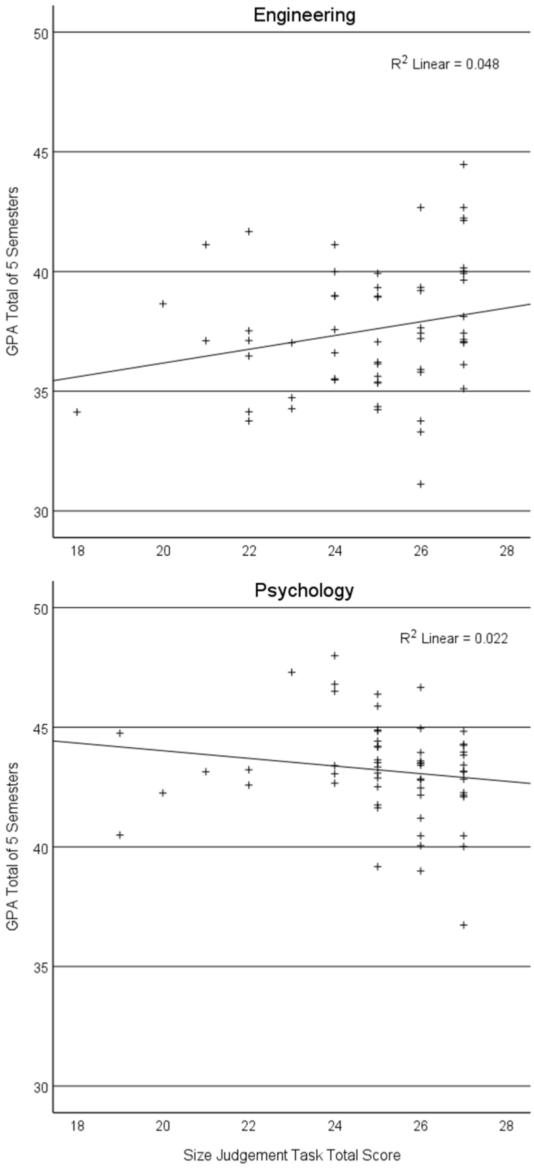

Fig. 2. Scatter plots showing the associations between size judggment performance and GPA for the two samples of students

IV. Discussion

It was hypothesized that inter-individual variation in visuospatial processing skill, in this case size perception, would be associated with academic achievement of engineering students. This is what was found: those students with the best size judgement skill tended to have the highest GPA scores. However, several interpretations need to be considered.

Firstly, is this a general effect, in that better visuospatial processing is simply better for achievement in higher education? This is a reasonable question to ask, as some other neurocognitive factors may have a general influence on achievement in higher education, such as general intelligence [3] response inhibition ability [4], or cerebral dominance patterns [5]. However, in the current research, the evidence suggests that it is not a specific factor, as it did not appear to be associated with GPA of psychology students. The extent to which size judgement ability may be linked specially to engineering is an open question, requiring further research. However, I tentatively suggest that visuospatial cognitive factors such as this may be more generally linked to what have been called things-based vocations, as opposed to people-based vocations [13].

A second issue relates to how likely it is that the visuospatial effect relates to demographic factors which vary substantially between things-based and people-based training courses. STEM courses, particularly engineering, are considered very things-based and also are associated with being taken up most commonly by men [14]. Male students also tend to outperform female students on visuospatial tasks [15], an effect that increases through child development, and is particularly strong in later adolescence, therefore including most undergraduate students [10]. However, the current findings suggest that the observations associations between size judgment skill and GPA of the engineering students, but not the psychology students, is not caused by age or sex difference between or within the groups. This can be argued because the effects did not alter when demographic factors were covaried within partial correlations.

A third issue is whether the observed association can be considered as specific to achievement in engineering, or merely reflects a different aspect of intelligence. This issue is more difficult to dismiss. Intelligence is a generally useful predictor of academic achievement. In fact, that was the original intended use of intelligence tests. The current research used a task that aligns more closely with the concept of an object-recognition system in the brain, supposedly independent of that underlying intelligence [11]. Nevertheless, it is a fact that all cognitive tests positively correlate with each other, an observation known as the positive manifold [16]. This is often taken to assume that all cognitive tests are measuring intelligence to some extent.

Nevertheless, the overlap between individual cognitive tests, such as the one used here, and intelligence, is only partial. It is therefore reasonable that some tests measure specific (non-intelligence) cognitive processes which are associated with achievement in specific contexts. Further research could ascertain whether visuospatial tasks, such as the one used here, can predict GPA above and beyond that explicable by standardized intelligence tests.

The current results should be considered in the light of some limitations. The samples used are relatively small, and may be somewhat specific to the geographic and socioeconomic context in which data were collected. In addition, the test that was used to measure size judgements was produced specially for this overall research study. Although this is a common way of investigation in cognitive sciences, use of a previously validated assessment tool would have enhanced the findings. In addition, the strength of correlations reported here may not seem particularly strong. The r value of .26 can be interpreted as explaining only about 7% of the variance in GPA in the engineering sample studied. On the other hand, this is a field in which low association strengths are the norm. The value reported here is, in fact, indicative of greater predictive power than is usually observed for intelligence testing in higher education [3], and is higher than the average correlation values reported in differential psychology research in general [17].

Despite the limitations, some tentative conclusions can be drawn. The use of specific cognitive assessments may be better than general assessments of performance, such as intelligence tests. It may be time for those in educational management to move away from screening college candidates with general-purpose intelligence tests. It is becoming clear that, the abilities that contribute to success within education and training vary with the subject matter.

Furthermore, if results such as those described here are replicated and extended, there may be potential for educational interventions. Cognitive abilities can generally be trained, and so it is possible that improving visuospatial skill would allow students to gain more from their formal training. There is already some existing research suggesting that such educational programs can be successful. One study has shown that training engineering students on visuospatial tasks is associated with gains in course grades in general [9].

Finally, to put the current work in a broader context, identification of performance factors that predict academic achievement can contribute to what has been dubbed educational neuroscience. This endeavor recognizes that an unfortunate gap exists between scientists and educators. On one side, the knowledge built up by cognitive and neuroscientists on learning, attention, memory etc. is potentially very useful in educational contexts, and on the other, the educators who could benefit from that are not trained with it. There is also of course an equally important reverse channel, where experiences of educators can inform academic theories of learning, attention, memory, etc.

The application of cognitive science to understanding educational outcomes, as attempted here, is a small step toward a more integrated and evidence-based pedagogy and more realistic and practical constraints on cognitive theory.

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