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Impact of Daylight on Learning Capabilities in European Schoolchildren

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Abstract

This paper will report on an extended analysis of a European research project with the aim of investigating the health impact of school environment in European schoolchildren. This project involved 38 partners from 25 countries. Overall, a total of 6174 children in 54 schools and 148 classrooms participated in the survey.

To further assess the impact of the indoor environment of school classrooms and its effect on student learning, about 46% of all the school children performed an attention/concentration exam that included a simple mathematical test and a logical test. Previous studies on learning capability and indoor climate parameters, such as daylight, usually refer to studies conducted in USA.

This paper will present the impact of daylight in the indoor environment of school classrooms and its effect on student performance. The analysis shows a positive relationship between light-related variables and performance, the most import determinant being the window to floor area ratio.

Keywords - schools; performance; daylight; indoor air quality

1. Introduction

The classroom indoor environment is known to have an effect on student performance. For example, studies on air quality in schools have observed that reductions in school performance can be expected for classrooms and buildings with higher levels of pollutants [1][2]. Other aspects of the indoor environment have also been investigated, such as lighting conditions inside the classroom. There are numerous benefits of both natural light and light and general, and the hypothesis that better lighting conditions lead to better results would seem obvious. However, previous studies have yet to come to a consensus on the issue of lighting and school performance. While evaluations of both natural daylighting and artificial lighting are suggestive of a link, the strength of that link remains unclear. Often these studies are limited geographically [3][4][5], or by a small number of students [6], suggesting further investigation is needed on a larger scale.

The present study investigates whether school performance is affected by the overall lighting conditions in the classroom. Students' exposure to light was determined using both direct and indirect assessments of lighting conditions from a European study conducted recently at the general population level. This study takes advantage of thousands of students in a European wide analysis and can control for other known predictors of student learning, including health, social status, and air quality.

2. Methods

2.1 Study Design

This study piggybacks on a large scale European cross-sectional investigation conducted in 2011 and 2012 to understand the health of schoolchildren and teachers' in relation to school environment in 23 countries across Europe. . Several environmental parameters (air quality, noise…) were objectively assessed in schools. Schoolchildren were assessed for general and respiratory health markers, and in some cases, also completed cognitive tests in order to investigate the effects of indoor pollutants on school performance. Questionnaires were given to teachers, parents and students, and several measurements of school characteristics and the general environment were also taken by an outside surveyor, including assessments on the lighting conditions in each classroom. We take advantage of these additional data by exploring possible relations between the lighting in school and test performance.

2.2 Population

The cross-sectional study design allows us to take a simultaneous picture of a phenomenon in a large geographical zone, covering 148 classrooms in 54 schools, evaluating 2,837 students in total with an age range of 7-13 years. There were approximately equal numbers of females and males, and of those who responded, the 82.5% were Caucasian, 1.9% Middle Eastern, 1.7% Black or Asian, and 12% other ethnicities.

We observed no demographic bias in the students who took performance exams as compared to the entire study. The ratio of each demographic (gender, race, education of mother) within the subgroup of test takers was similar to that of the larger project as a whole. We also do not observe any bias in terms of classroom characteristics such as ceiling height, window area or floor area, as they are the essentially the same for both groups

2.3 Light Assesment

Classroom characteristics relating to the lighting conditions included several parameters. The ceiling height, floor area and window area were recorded, as well as the percentage of window area facing north, south, east or west. The orientation of the windows was considered as a binary variable, representing either a view on green space or a view on a street or another building. Direct sunshine on the benches in the classroom was also considered as either yes or no. Concerning the windows themselves, the type of lighting (natural, artificial or a mixture), the type of glazing (single, double, triple, double clear with filling or double clear with coating), the type of shading (internal, external, none or south-side only) and the ability to open the windows (all, some, not allowed) were also included.

Other indicators of daylight, such as average national latitude and season, were also taken into account. As a measure of the amount of natural light available, a daylight index was introduced to account for the number of hours the sun was up for a given location. This index is highly correlated with season, and ranges from 1-13, where 1 represents the darkest four weeks of the year and 13 represents the lightest four weeks of the year. The index is the same for everyone regardless of latitude, and is calculated based on the test date alone.

Another measure included is the window to floor area ratio, which is simply a measure of how "big" the windows are compared to the classroom size. This variable was introduced because the window area alone does not well describe the amount of natural light for a given space.

Many of our variables are related to the windows and therefore indicative of the natural light available. We therefore consider the overall lighting conditions as a contribution of both natural and artificial sources rather than try to distinguish between the two.

2.4 Performance Exams

Performance in the classroom was measured by means of an exam consisting of math and logic exercises. The exams were given at the beginning of the school day. The first section tested basic arithmetic skills and was graded as a percentage of correct answers. The second part of the exam tested logical translation skills and consisted of 119 elements to be completed within 120 seconds. This section tested both logic and memory. Here again, the score was based on a percentage of correct answers. The final score used in the analysis was an overall percentage of both sections. The test did not differ for children in different grade levels.

Two different versions of the test (Test 1 and Test 2) were administered in different countries (see Table 1), with the exception of Serbia, where students took both versions. Aside from the detail presented in Table 1, both Test 1 and Test 2 are treated as a single test, since the basic content was similar even if individual questions were different. There was no difference in the demographics of the test takers according to the type of tests.

Table 1. Number of Students and Test Scores for each of the two performance exams used.

	Test 1	**Test 2**
Number of Students	1788	1292
% of Test Takers	63.2%	45.5%
Age Range	8-13	7-13
Number of Countries	8	5
Countries	Albania Belgium Bosnia & Herzegovina Estonia France Greece Hungary Serbia	Czech Republic Italy Lithuania Portugal Serbia

2.3 Statistical methods

Classical analysis was applied. In particular, Each of the indicators of lighting conditions was first checked for a crude association with the mean score. For this we used either a univariate regression model for continuous variables (which looked for a linear relationship between the variable and the average score), or ANOVA or t-test for categorical variables, which identified whether or not the overall mean of the exam scores between the differing groups was significantly different. Multivariate linear models were used for assessing the relationship between light variables and performance after considering confounders.

All analyses were done using Stata 14, taking advantage of pre-programmed statistical packages.

3 Results

3.1 Descriptive Analyses

The exam score distributions for Test 1, Test 2 and for both tests combined are shown in Figure 1. The distributions and mean scores are similar for all three groups. In total, 2831 scores, one for each student, were used in the final analysis.

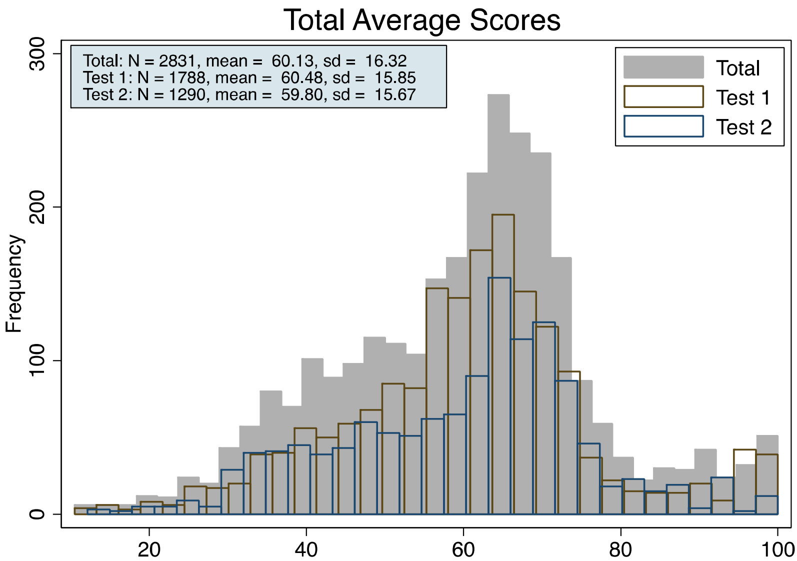

Figure 1. Total average test score for Test 1 (brown), Test 2 (blue) and for all students (grey). These scores represent the percentage of correct answers for both sections of the exam

3.1 Univariate Analyses

We find that several variables show a significant ($P < 0.05$) association with the average exam scores with the exceptions of window orientation and floor area. The percentage of window area facing north, east or west are also not significant, however the percentage of window area facing south was. The strength of the associations between each of the significant continuous variables and the mean exam scores are given in Table 2.

Table 2. Strength and Significance of the association between the continuous lighting indicators and the mean score. The coefficient represents the strength of association.

Variable	Coeficient	SD	t	P	CI (95%)
Celing Height	-5.751	.696	-8.27	0.000	-7.11 - 4.38
Window Area	.1799	.0318	5.65	0.000	.118 - .242
Window/Floor Area Ratio	29.239	2.939	9.95	0.000	23.477 - 35.002
% Window Facing South	.112	.00923	12.06	0.000	.0938 -.1303
Daylight Index	-.9435	.1311	-7.20	0.000	-1.201 -.6865
Latitude	1.14967	.0481	23.89	0.00	1.055 - 1.244

The strongest predictor of performance was the window to floor area ratio. The strength of this association persisted in a multivariate linear regression analysis.

We find that average scores were higher during autumn and winter months. There is also a slight but significant effect of of latitude, average scores in northern countries. We find no difference in scores between classrooms which face urban settings and those settings. We see only a very slight difference on window area alone, but a high significance on the impact of the window to floor area.

3.2 Multivariate Analysis

Variables with significant association in the univariate analysis were then analyzed further to understand the overall influence these indicators have in student performance. Some categorical variables were encoded by number in order to be used in a linear regression. A stepwise multivariate linear regression was performed on the mean exam score using the indicators listed in Table 3. Variables which were no longer significant at the 0.05 level were excluded, as indicated in Table 3.

Table 3. Results from a stepwise multivariate linear regression on the mean exam score.

Variable	Coefficient	SD	t	P	CI (95%)
Window/ Floor Area Ratio	12.251	2.838	4.32	0.000	6.684 17.82
Type of Shading	3.525	.4131	8.53	0.000	2.715 - 4.335
Latitude	.7903	.0587	13.46	0.000	.6752 - .9055
% South	.0450	.0097	4.67	0.000	.0261- .0640
Daylight Index	-1.238	.1407	-8.80	0.000	-1.514 - .9621
Direct Sunlight	-1.998	.6762	-2.95	0.003	-3.324- .6716
Story Number	Excluded			0.2491	-
Glazing	Excluded			0.4117	-
Ceiling Height	Excluded			0.4486	-
Openable Windows	Excluded			0.4875	-

We find that when all light indicators are included, the positive influence from the window to floor area ratio dominates, followed by the type of shading, the latitude, and finally the percentage of window area facing south. We find that the daylight index shows a negative effect, as does the existence of direct sunlight. Together these indicators explain 22% of the variation between student scores.

3.3 Models adjusted for counfounders

We adjusted on ethnic group, education of the mother and number of students in the classroom. By including these variables, we were able to increase explain 25% of the variation between exams scores, however the direct sunlight was no longer significant. We also found that the education of the mother and the race were not significant indicators of performance. Gender was significant (P = 0.031) and suggested females score 1.45 times better on average. The window to floor area ratio remained the strongest indicator of student performance, with a coefficient of 10.673 (P = 0.001).

4 Conclusions and Discussion

Our data from a European multicentric survey shows that the lighting conditions have a significant influence on student performance. In particular, we find a positive association between the window to floor area ratio and student scores and a weaker but significant positive association with the percentage of window area facing south. As the window to floor area ratio is a measure of how large a window is for a given space, we conclude that larger windows have a positive effect on students. This may be a result of abundant light, but may also be an indication that students who feel less closed in are more relaxed and can concentrate on their school work. We did not have information on the height of the windows, so we are unable to determine if the ability to look outside is important. The small, but positive influence on scores with the percentage of windows facing south suggests that natural light is indeed a factor.

We also find a significant association found between the type of window shading. Classrooms with internal shading, and south side shading had significantly higher average scores than did those with external or no shading, suggesting that it is advantageous to control the amount of sunlight entering the classroom. If glare is indeed a problem for some classrooms, as implied by the fact that we see a negative association with having direct sunlight available. A similar negative association between direct sunlight was seen by [3], which found that students in classrooms with diffuse natural light performed better.

The average national latitude was included in order to understand any differences between students who live with differing amounts of daylight during winter months. As most of the exams were taken during the winter, the amount of sunlight hours varies greatly between our most northern countries, Estonia and Lithuania, and the most southern, Greece and Portugal. We find that students in the northern countries performed better, however this could have been predicted based on PISA ranking [7]. We also observe that students performed better during darker months, based on the negative association with the daylight index. However this doesn't necessarily mean winter – mean scores during autumn months were higher than winter months.

Other factors that were significant when checked directly against the mean exam scores with a univariate model, but did not remain significant when other light indicators were included, are story number, type of glazing, ceiling height and openable windows. We do see a significant difference in average scores between single, double and triple glazed windows, however this may be a signal of an affluent neighborhood rather than an effect due to the glazing itself.

We do not observe an impact on performance from the orientation of the windows, suggesting that students performance was not affected by windows that face concrete or green spaces. We should note however, that since window height was not included in the data, we could not determine if the students were able to see out the windows from their seats.

Our results are not comparable with the previous rare studies on the same topic, due to differences in populations and methods. Also because we did not assess light and illumination objectively. As another strength, we used several variables to assess light and we used European data. In addition, we found high statistical significance in the case of same variables. However, further studies are necessary to better determine the role that light can have in schools.

To sum up, our European data support the hypothesis that light is important for learning capacities and performance of schoolchildren.

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