THE EFFECT OF LOW VENTILATION RATES ON THE COGNITIVE FUNCTION OF A PRIMARY SCHOOL CLASS

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MANAGEMENT SUMMARY

Several studies have suggested that recommended ventilation rates are not being met within schools. However these studies have not included an evaluation of whether or not this failure might have an impact on pupil performance and learning outcome. The work reported here was designed as an initial investigation into this question.

Using standardised, computerised tests of cognitive function, this study demonstrates that the attentional processes of school children are significantly slower when the level of CO_2 in classrooms is high. The effects are best characterised by the Power of Attention factor which represents the intensity of concentration at a particular moment, with faster responses reflecting higher levels of focussed attention. Increased levels of CO_2 led to a decrement in Power of Attention of approximately 5%. Thus, in a classroom where CO_2 levels are high, students are likely to be less attentive and concentrate less well on what the teacher is saying, which over time may possibly lead to detrimental effects on learning and educational attainment. The size of this decrement is of a similar magnitude to that observed over the course of a morning when students skip breakfast.

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INTRODUCTION

Ventilation within schools is important for at least two reasons. Firstly, there is the question of air quality and its effect on health and performance. Secondly, it is a heat loss path. There is varying evidence on the effect of low ventilation rates on performance and health [Myhrvold, 1996; Smedje 1996] and student attendance [Shendell, 2003], and clearly more work needs to be done. Ultimately it will be concerns in this area that will set ventilation rate guidance.

The role of ventilation as a heat loss path has become more important as school design has improved. A combination of the building regulations and desires of local authorities to address issues of sustainability, and in particular climate change caused by anthropogenic carbon emissions, has led to improved levels of insulation. In turn, this has led to the ventilation path becoming a more prominent heat loss path; although improvements in window design have reduced uncontrolled leakage.

Recommended fresh air supply rates for school classrooms are country-specific. For the UK, the recommendations are enshrined in Building Bulletin 87 (BB87), which requires a background fresh air supply rate of 3 litres per second per pupil ($l\ s^{-1}p^{-1}$) with the capacity to supply 8 $l\ s^{-1}p^{-1}$. The value of 8 $l\ s^{-1}p^{-1}$ is used because it implies the concentration of CO_2 in a fully occupied classroom can never exceed 1000ppm, however long the room is occupied.

At least three studies have suggested that these levels are not being met [Coley, 2000; Beisteiner, 2000; Lugg 1999]. However such work did not include an evaluation of whether or not this failure might have an impact on performance. The work presented here, which was sponsored by the Department for Education and Skills, was designed as an initial investigation into this question. The was achieved by varying levels of CO_2 within a classroom and investigating the cognitive performance of the schoolchildren present using a well-validated computerised battery of tests measuring memory, attention and subjective mood.

METHOD

Eighteen schoolchildren between the ages of ten and eleven were recruited from a single class at Topsham Primary School, Devon (Figure 1). This school was selected because it represents a typical modern design and had proved to be ventilated below that required by BB87 [Coley, 2000; Beisteiner, 2000]. This allowed the study to be presented as an attempt to improve the ventilation within the school and to investigate the impact of such an improvement.

Figure 1. The selected school.

The purpose of the study was described in detail to the participants, the classroom teacher, the head teacher and the local educational authority. As the experiment involved opening the windows to produce a high ventilation (low CO_2) situation and closing them to produce a low ventilation (high CO_2) situation, it was unlikely that the pupils were not be aware of the details of the experiment.

The room selected (Figure 2) is cross ventilated with windows in opposite walls, was built in 2001 and of dimensions 8.2 by 6.2 by 3.9m high, or 198 m^3 in volume. Temperature was maintained by the use of a freestanding air conditioning unit with no exchange of air to the outside. On random days the classroom windows were either closed or opened to create the designed level of CO_2. Pupils were selected at random and were unpaid. No CO_2 was injected into the classroom from another source. All tests were performed in the classroom during the morning period after CO_2 levels had stabilised. Figure 3 shows the CO_2 and temperature scatter during the tests. (Both these parameters were measured using a Talaire 7001.) From this plot it is clear that the temperature was well maintained, with low CO_2 days not equating to elevated temperatures, and that there are two clearly identifiable CO_2 regimes which are well separated. As the concentration was slow varying and the test period short, for each test the CO_2 concentration at the start of the test was assumed to be representative of the test period.

Two training sessions were performed in the week prior to testing to familiarise participants with the CDR battery and to reduce practice effects. The CDR battery was performed daily by each participant, with concurrent CO_2 measurements, for 10 schooldays over three weeks

Figure 2. The selected classroom.

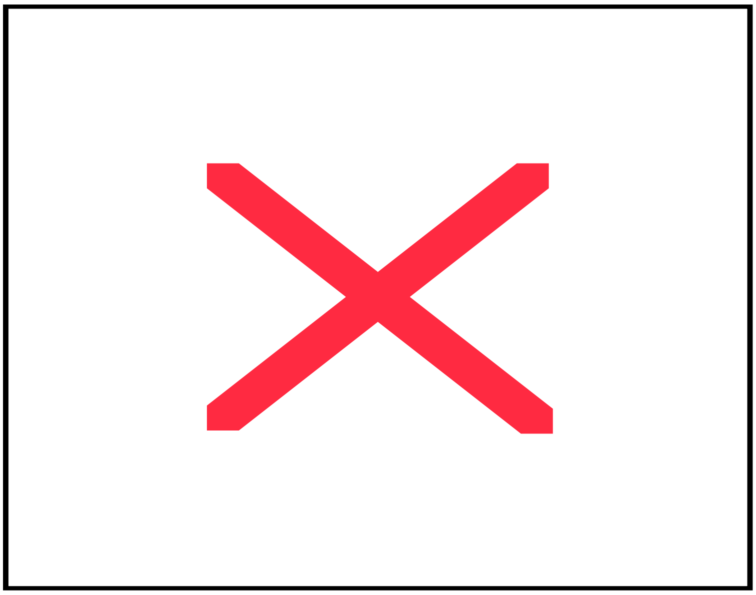

Figure 3. CO_2 and temperature history during the tests.

COGNITIVE ASSESSMENT

A battery of tasks from the Cognitive Drug Research (CDR) computerised cognitive assessment system was administered. The CDR system has been widely used in clinical research and validated for use with a number of different populations, including children [Wesnes, 2003]. All tasks were computer-controlled, with the information presented on the screen of a laptop computer and the responses recorded via a response module containing two buttons, one marked 'NO' and the other 'YES'. The battery took approximately ten minutes to complete; the tasks in order of administration are described in Table 1. Participants were tested in groups of four to six at each test session, with the individual laptop computers arranged so that participants could not view the screens of others. Parallel forms of the CDR tests were presented at each test session to allow for repeated testing by presenting different, but equivalent, stimuli at each administration.

Task	Description
Picture Presentation	A series of 20 pictures was presented on the screen at the rate of 1 every 3 seconds for the participant to remember.
Simple Reaction Time	The participant was instructed to press the 'YES' response button as quickly as possible every time the word 'YES' was presented on the screen. Thirty stimuli were presented with a varying inter-stimulus interval.
Digit Vigilance	A target digit was randomly selected and constantly displayed to the right of the screen. A series of digits was then presented in the centre of the screen at the rate of 150 per minute. The participant was required to press the 'YES' button as quickly as possible every time the digit in the series matched the target digit. There were 45 targets in the series and the task lasted for 3 minutes.
Choice Reaction Time	Either the word 'NO' or the word 'YES' was presented on the screen and the participant was instructed to press the corresponding button as quickly as possible. There were 30 trials for which each stimulus word was chosen randomly with equal probability, with a varying inter-stimulus interval.
Picture Recognition	The original pictures plus 20 distracter pictures were presented one at a time in a randomised order. For each picture the participant had to indicate whether or not the they recognised it as being from the original series by pressing the 'YES' or 'NO' button as appropriate, as quickly as possible.
Bond-Lader Visual Analogue Scales of Mood and Alertness [Bond, 1974]	A computerised version of the 16 questionnaire items was employed. Participants indicated their responses along the analogue scale using a mouse. The 3 factors of self-rated Alertness, Calmness and Contentment were derived.

Table 1: Description of the battery of tasks, in order of administration

MEASURES

The reaction times and accuracy scores from the CDR tasks, and the visual analogue ratings of Alertness, Calmness and Contentment were selected for analysis. In addition, the two factors of Power of Attention and Continuity of Attention were calculated to further characterise the data. The factors have been derived previously from a principal components analysis of the CDR system, and used to assess treatment effects.

Power of Attention consists of the speed measures from the Simple Reaction Time, Choice Reaction Time and Digit Vigilance tasks. In these tasks, speed reflects the intensity of concentration at a particular moment; the faster the response, the more processes that are being brought to bear upon the task. In everyday terms, this reflects high levels of focussed attention, for example, ‘straining to hear a sound’, ‘peering closely at an object of great interest’, or ‘listening intently to someone speaking’.

Continuity of Attention consists of the accuracy measures from the Choice Reaction Time and Digit Vigilance tasks, reflecting the ability of the participant to sustain attention and avoid error. Examples of this might be reading a long section of a book without looking up, or playing a game for a long time without being distracted.

ANALYSIS

As the examination of the distribution of recorded CO_2 measurements showed a clear clustering of readings below 1000 ppm and above 2000 ppm, the dichotomy of low and high CO_2 conditions was used to classify the test sessions for analysis.

Repeated measures ANCOVA was conducted using the PROC MIXED procedure of the SAS system. Fixed terms were fitted to the model for CO_2 level, test session and the CO_2 level session interaction. A random effect of participants-within-CO_2 level was fitted to the model. Significance of the interaction was tested at the 0.05 level. All testing was two-tailed. If the interaction was found to be significant, comparisons were conducted between the high and low CO_2 conditions at each test session, using the t-test option from the LSmeans statement. If the interaction was not found to be significant, the main effect of CO_2 level was tested at the 0.05 level. If the main effect of CO_2 level was found to be significant, comparisons were conducted between the high and low CO_2 conditions overall. Analyses were performed on all collected data.

RESULTS

Participants completed an average of 4 test sessions in both the low (mean CO_2 level 690±122, range 501-983 ppm) and high (mean CO_2 level 2909±474, range 2096-4140 ppm) CO_2 conditions. These conditions equate to ventilation rates of 13 and 1.5 l/s per pupil.

Significant effects of CO_2 level were observed on the reaction time scores of the Simple Reaction Time task ($F(1,141) = 5.2$, $p = 0.02$), with results approaching significance for Choice Reaction Time ($F(1,141) = 3.6$, $p = 0.06$) and Digit Vigilance Reaction Time ($F(1,141) = 3.2$, $p = 0.08$). This was reflected in the highly significant effect on Power of Attention ($F(1,141) = 8.5$, $p = 0.004$). In all cases, reaction times were prolonged when CO_2 levels were high. No significant effects were observed on the accuracy scores from the Choice Reaction Time task, Digit Vigilance, or the Continuity of Attention factor. There were no significant effects of CO_2 on memory as measured by the Picture Recognition task. In relation to self-reported mood, there was a significant effect on Calmness ($F(1,136) = 5.98$, $p = 0.02$) with participants reporting that they felt calmer in the high CO_2 condition. Results of the LSmeans t-test comparisons are shown in Table 2.

Task	Low CO_2		High CO_2		t	p
Simple Reaction Time	376	(92)	404	(110)	-2.28	0.02
Digit Vigilance RT	503	(55)	514	(54)	-1.79	0.08
Digit Vigilance accuracy	78.3	(14.1)	77.2	(14.4)	0.78	0.44
Digit Vigilance false alarms	12.8	(26.9)	16.5	(32.9)	-0.80	0.43
Choice Reaction Time	544	(113)	573	(126)	-1.89	0.06
Choice Reaction Time acc.	89.4	(8.2)	89.1	(7.9)	0.31	0.75
Picture Recognition RT	977	(218)	1065	(534)	-1.45	0.15
Picture Recognition acc.	50.6	(23.3)	49.1	(25.6)	0.36	0.72
Power of Attention	1423	(213)	1491	(222)	-2.92	0.004
Continuity of Attention	49.3	(27.9)	44.9	(34.3)	1.00	0.32
Alertness	59	(20)	58	(23)	0.60	0.55
Calmness	53	(19)	59	(18)	-2.45	0.02
Contentment	67	(19)	69	(19)	-1.15	0.25

Table 2: LSmeans t-test comparison of cognitive function and mood between the low and high CO_2 conditions. Data shown are means and (SD). Acc. = accuracy scores; RT = reaction times in ms.

DISCUSSION

Using standardised, computerised tests of cognitive function, this study demonstrates that the attentional processes of school children are significantly slower when the level of CO_2 in classrooms is high. The effects are best characterised by the Power of Attention factor which represents the intensity of concentration at a particular moment, with faster responses reflecting higher levels of focussed attention. The increased levels of CO_2 led to a decrement in Power of Attention of approximately 5%. The size of the decrement associated with poor ventilation is of a similar magnitude to that observed over the course of a morning when students skip breakfast [Wesnes, 2003]. Thus, in a classroom where CO_2 levels are high, students are likely to be less attentive and concentrate less well on what the teacher is saying, which over time may possibly lead to detrimental effects on learning and educational attainment.

The effects of high levels of CO_2 on attention seen here are in agreement with a previous study that found a negative correlation between increasing concentrations of CO_2 and performance on similar cognitive tests (simple reaction time, choice reaction time and the colour- word test of vigilance) [Myhrvold, 1996].

FUTURE WORK

There are several questions left outstanding by this work:

1. How does the measured level of performance decline translate into educational disbenefit?
2. Is carbon dioxide the cause of the decline, or is it simply a proxy for low ventilation rates and the build-up of other compounds?
3. What is the exact form of the functional relationship between carbon dioxide concentration and performance? In particular the relationship between 3 and 8 l/s per pupil. Answering this question would require the use of more controlled studies using a greater number of pupils.
4. Nationally, what impact are low ventilation rates in schools having upon pupils?

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