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Prediction of changes in working memory and associated changes in educational attainment in Greater Manchester primary schools following changes in air quality

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Summary

- Working memory is a good indicator of academic achievement.
- Based on results from a longitudinal study of air pollution and cognitive performance in primary school children, we estimate the impact of changes in air pollution (outdoor NO_2 and indoor PM2.5) on working memory
- Based on the Spanish study, we assume that the working memory of school children in a relatively low pollution environment will increase by 48, as measured by the 2-back d' multiplied by 100, over a 12-month period.
- If air pollution outside of school, measured by NO_2, increased by 20%, this would result in an increase in working memory of only 45.1, a reduction in the growth of 6.1% (95% CI: 1.1% to 10.9%) compared to the low pollution scenario.
- Assuming linear growth, this means that a 20% increase in outdoor NO_2 pollution reduces development by around 3 weeks in a 12-month period.
- If NO_2 pollution outside of school increased by 50%, the 12-month increase in working memory reduces to 40.7, a reduction in the growth of 15.2% (95% CI: 2.8% to 27.1%).
- Assuming linear growth, this means that a 50% increase in outdoor air pollution reduces development by around 7 weeks in a 12-month period.
- We observe similar effects, albeit slightly smaller, for indoor air pollution, as measured by PM2.5.

Introduction

In this document, we present results from some modelling analyses where we examine plausible responses in working memory in primary school children following hypothetical changes in air pollution. We base our models on estimates from the published literature, in particular two papers from the same study in Barcelona. In both cases working memory in primary school children (around 8 and a half years of age) was assessed repeatedly over a 12-month period, using the 2-back d' score, multiplied by 100.

We initially consider changes in outdoor air quality (measured outside of the school, i.e. in playgrounds) and then consider changes in indoor air quality (measured inside the school, i.e. in classrooms).

All of the resulting models are based on a number of assumptions:

- That primary school children, their families, their development, and their education are similar across the sites where the estimates come from (mainly Barcelona) and Greater Manchester (GM). All of the estimates we consider are based on analyses that control for these factors, hence we feel more comfortable making *ceteris paribus* comparisons.
- That changes in air quality across the settings (Barcelona and Greater Manchester) are comparable. To further help with this assumption, we predominantly focus on relative changes, expressed in terms of percentage increases/decreases.
- That the relationships are linear; that is a yearly change is consistent (i) between months in the year and (ii) between years. These linearity assumptions were present in the papers we base our scenario modelling on.

Results are presented as change in working memory over a period of 12 months. In this age group working memory will improve with age, and the results are presented as a change from the increase in working memory that would be expected.

The effect of increased outside air pollution (Measured by NO_2) on working memory

Using the estimates from the Sunyer et al. (2015) paper, we calculated a plausible risk function, both in terms of absolute changes in outdoor NO_2 (i.e. in µg/m^3) and in percentage changes in outdoor NO_2. For ease of interpretation., we focus on percentage changes in NO_2 – i.e. we are concerned with relative changes in exposure.

In the Sunyer et al. (2015) model, an interquartile range (IQR) reduction in outdoor NO_2 pollution indicated a 46% reduction in outdoor NO_2 from median levels ((57.4-35.1)/48.5; Table 3 of Sunyer et al., 2015). This 46% reduction lead to an additional (over and above what is expected) increase in working memory of 6.6, or 14%, in a 12-month period (95% CI: 2.5% to 25.0%; Table 6 of Sunyer et al., 2015).

In Table 1, we consider a number of scenarios that could happen in Greater Manchester. We replicate the difference in the Sunyer et al. paper, and then consider a number of percentage ***increases*** in outdoor NO2 levels: 20%, 30%, 40%, and 50%. In each case we report the expected penalty to the percentage change improvement in working memory and the 95% CI. These 12-month reductions in working memory are shown graphically in Figure 1, where we plot the changes in working memory.

Scenario	Change in working memory over 12 months compared to no change in NO_2	95% CI
Increase by 46%	-14%	-2.5% to -25%
	Predictions	
Increase by 20%	-6.1%	-1.1% to -10.9%
Increase by 30%	-9.1%	-1.6% to -16.3%
Increase by 40%	-12.2%	-2.2% to -21.7%
Increase by 50%	-15.2%	-2.8% to -27.1%

Table 1: Estimated change in working memory following hypothetical increases in outdoor NO2. Percentage change in the second column is to be interpreted as the change from 'do nothing'. That is, we assume that children will experience an increase in working memory over a 12-month period, and these effects are the reduction in this 'natural improvement'.

For example, a 20% increase in NO_2, from median levels, will lead to a reduction in working memory of 3, or 6.1%, in a 12-month period (95% CI: 1.1% to 10.9%). A 50% increase in NO_2 will lead to a reduction in working memory of 7.3, or 15.2%, in a 12-month period (95% CI: 2.8% to 27.1%).

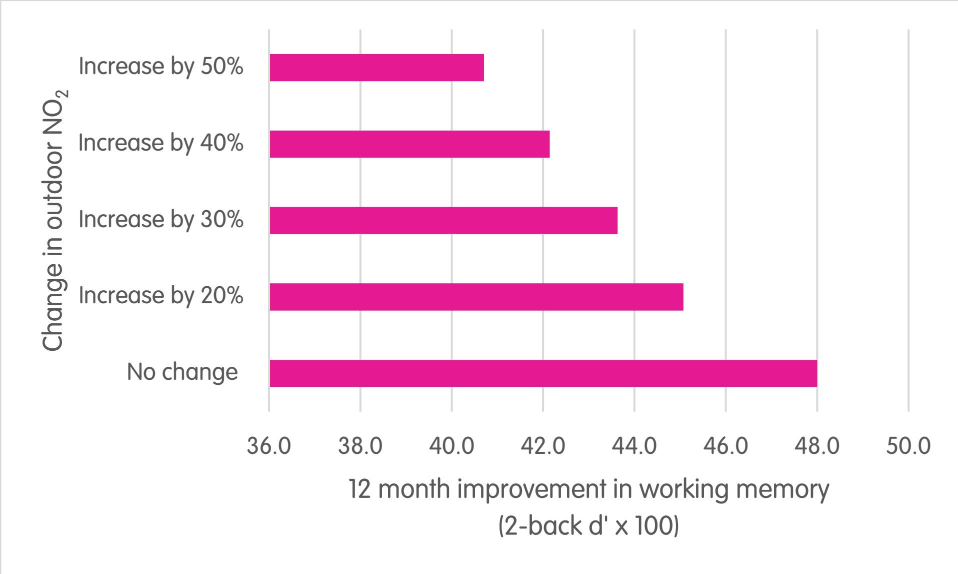

Figure 1: The effect of outdoor NO_2 on working memory (2-back, d' x 100) in a 12-month period. ***Notes: the y-axis lists a number of hypothetical scenarios for outdoor NO_2 increases, the x-axis shows the 12-month change in working memory (2-back d' x 100). The baseline of 'no change' is based on the Barcelona studies of Sunyer et al (2015) and Basagana et al. (2016).***

The effect of increased inside air pollution (measured by $PM_{2.5}$) on working memory

Basagana et al. (2016) examine the relationship between, *inter alia,* indoor air pollution and working memory (using the same 2-back memory test). Their measure of indoor pollution is $PM_{2.5}$ and they additionally individually consider different aspects of indoor $PM_{2.5}$. They find "*An interquartile range increase in **indoor traffic-related** PM2.5 was associated with reductions in cognitive growth equivalent to 22% (95% CI: 2%, 42%) of the annual change in working memory […]*".

They do not find a statistically significant relationship between any other sources of indoor $PM_{2.5}$ and hence we focus on traffic related indoor $PM_{2.5}$ here.

In the Basagana et al. (2016) model, an interquartile range (IQR) reduction in indoor traffic related $PM_{2.5}$ pollution indicated an 86% reduction in outdoor $PM_{2.5}$ from median levels ((6.8-3.9)/4.4; Table 4 of Basagana et al., 2016). This 86% reduction lead to an increase in working memory of 22% in a 12-month period (95% CI: 2.0% to 42.0%; Table S3 of Basagana et al., 2016)).

In Table 2, we consider a number of scenarios that could happen in Greater Manchester. We replicate the difference in the Basagana et al. paper, and then consider a number of percentage ***increases*** in indoor traffic-related PM2.5 levels: 20%, 30%, 40%, and 50%. In each case we report the expected penalty to the percentage change improvement in working memory and the 95% CI. These 12-month reductions in working memory are shown graphically in Figure 2, where we plot the changes in working memory.

For example, a 20% increase in traffic related indoor $PM_{2.5}$, from median levels, will lead to a reduction in working memory of 2.5, or 5.1%, in a 12-month period (95% CI: 0.5% to 9.7%). A 50% increase in $PM_{2.5}$ will lead to a reduction in working memory of 6.1, or 12.8%, in a 12-month period (95% CI: 1.2% to 24.4%).

Scenario	Change in working memory over 12 months compared to no change in $PM_{2.5}$	95% CI
Increase by 86%	-22%	-2% to -42%
	Predictions	
Increase by 20%	-5.1%	-0.5% to -9.7%
Increase by 30%	-7.7%	-0.7% to -14.7%
Increase by 40%	-10.2%	-0.9% to -19.5%
Increase by 50%	-12.8%	-1.2% to -24.4%

Table 2: Estimated change in working memory following hypothetical increases in indoor traffic related PM2.5. Percentage change in the second column is to be interpreted as the change from 'do nothing'. That is, we assume that children will experience an increase in working memory over a 12-mponth period, and these effects are the reduction in this 'natural improvement'.

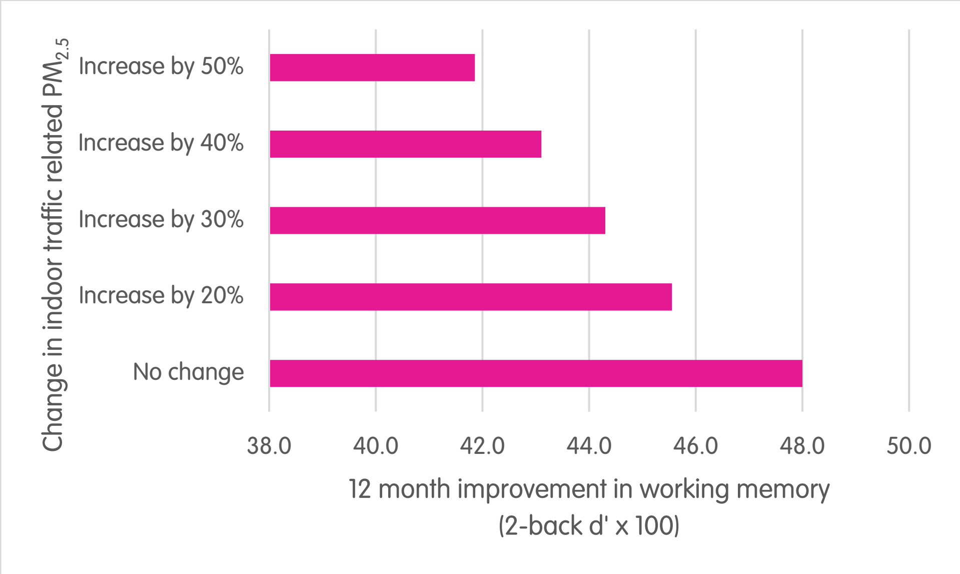

Figure 2: The effect of traffic related indoor PM2.5 on working memory (2-back, d' x 100) in a 12-month period. Notes: the y-axis lists a number of hypothetical scenarios for indoor traffic related $PM_{2.5}$ increases, the x-axis shows the 12-month increase in working memory (2-back d' x 100). The baseline of 'no change' is based on the Barcelona studies of Sunyer et al (2015) and Basagana et al. (2016).

The effect of air pollution on the trajectory of working memory over 12-months

Using the estimates from the Sunyer et al. (2015) paper, and our scenario modelling above (Table 1 and Figure 1), we examined the trajectories in working memory over a 12-month period. To do this, we had to assume that the trajectory was linear; that is, it increases at a constant rate over the 12-month period.

Figure 3 plots the expected trajectories in the improvement in working memory in a 12-month period. The *x-axis* displays each of the twelve months and the *y-axis* displays the improvement (from baseline) in working memory (measured by the 2-back d' x 100). The trajectories (or slopes) start at the origin as in month zero there is no improvement. We plot three trajectories: (1) the baseline 'do nothing' scenario; (2) if there was a 20% increase in outdoor NO_2; and (3) if there was a 50% increase in outdoor NO_2.

We estimate that a 20% increase in outdoor NO_2 would slow down the development of working memory in children by around three weeks (Figure 3). A 50% increase in outdoor NO_2 would slow down the development of working memory in children by around seven weeks (Figure 3).

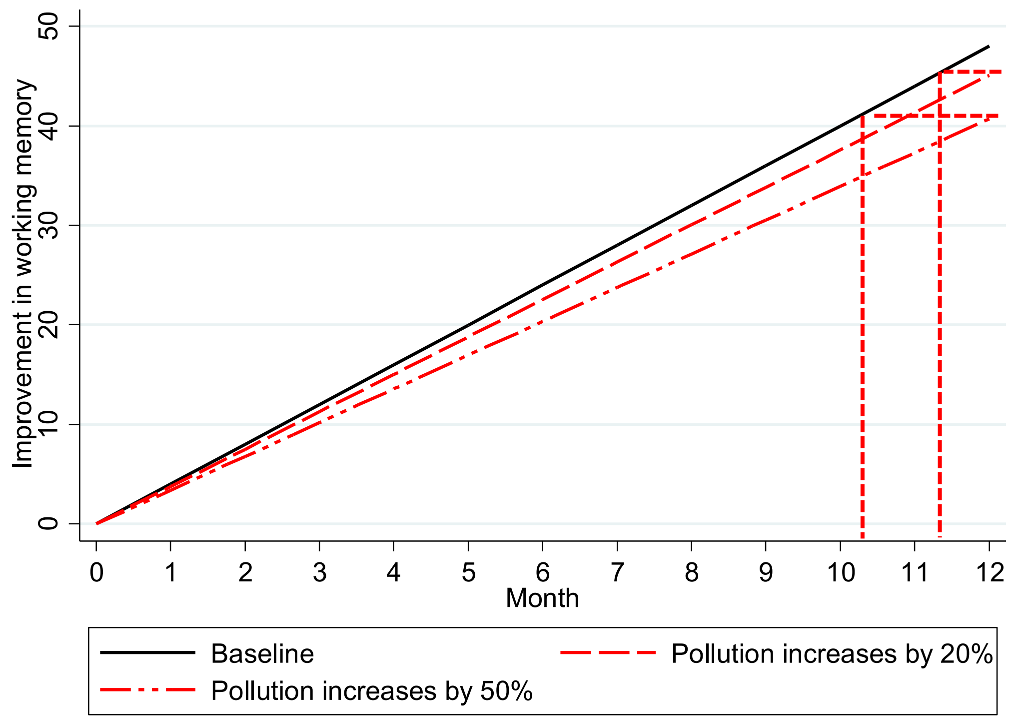

Figure 3: The effects of outdoor air pollution (measured by NO_2) on the development of working memory in children.

The effect of working memory on educational performance

A meta- analysis by Cortés Pascual et al. (2019) found that working memory is a good predictor of educational performance.

Therefore, from the above information, we can see that an increase in air pollution, will result in a reduction of working memory, which is associated with a reduced educational performance. Based on the information available currently available to us, we cannot exactly quantify the relationship in for primary school children in Greater Manchester (this would require detailed information on the distribution of individual educational performance or underlying test scores across Greater Manchester by age and gender). However, we can conclude that the reduced development in working memory attributable to worse air pollution is very likely to translate reduction in educational performance and possibly also educational attainment.

Discussion

In this document we set out some estimated effects on working memory following changes in air quality. We show that increased air pollution would lead to a slower development in working memory. We then state the link between working memory and educational performance and infer that increased air pollution will lead to a slowing down in the development of educational performance compared to no increases in pollution.

However, as with all modelling analyses, the outputs ('predictions') are only as good as the inputs, and the extent to which they are comparable and generalisable between settings and contexts. Further analysis is required to assess how similar Greater Manchester and Barcelona are.

Future work

The true associations between pollution and educational attainment in Greater Manchester can only robustly be analysed using a randomised controlled trial with intervention and control schools.

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