The power of sound – can we hear air pollution?

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Abstract

Reducing air pollution sources and air pollution exposure is an important challenge, particularly for the very young and very old, who are more susceptible to the health effects of such pollution. However, air pollution sensors can be expensive (for primary school budgets) and hard to interpret, whereas data from a sound (loudness) sensor can be interpreted much more easily and sound sensors are much cheaper. In this study we compare a carbon monoxide (CO) pollution sensor with a sound sensor in a number of investigations around an urban primary school, and find that the sound sensor is a very good proxy for CO (a marker of air pollution). Therefore, we propose that a sound sensor can be used in an urban primary school setting to investigate polluted and non-polluted environments.

Keywords: Sound, air pollution, data loggers, outdoor learning, science enquiry, climate science

Introduction

Before moving on to the application of sound sensors as a proxy for measuring air pollution, we will provide a short introduction to the science of sound. Sound is a form of energy that travels through a medium. Sound waves are transferred by a particle in that medium passing the energy on to another particle. Sound travels differently depending on how tightly packed the particles are. In a solid, particles are very close together and so sound can travel through that medium very efficiently. In a liquid, where the particles that comprise it tend to be further apart, sound can travel through this medium, but not as efficiently as it can in a solid. Therefore, in a gas, where particles are much further apart than in a solid or a liquid, we would expect sound to travel least efficiently. Sound cannot be transferred in a vacuum because there is an absence of particles to travel through.

Table 1 demonstrates that the speed of sound is slowest through air. The structure of the solids must be different, because sound travels much faster through steel than through wood. Wood is an example of a polymer (e.g. Shallcross *et al*, 2016), which consists of long chains of particles, whereas steel is a metallic solid and consists of a regular structure, which makes it easier for sound to be passed on from particle to particle.

In the animal kingdom, there are variations in the range of sounds that can be heard, as shown in Table 2. The human hearing range is between around 64 Hz (low frequency or pitch sound) and 23,000 Hz or 23 kHz (high frequency or pitch sound). Interestingly, dogs have a similar lower frequency level to, but a much higher upper frequency threshold than, humans, and anyone who has had a dog will know that they can hear sounds that humans cannot. Bats have a high frequency threshold, which they use

Material	Speed of sound / ms^{-1}
Air	332
Water	1501
Wood (oak)	3850
Steel	5960

Table 1. Speed of sound in different materials at 300 K or 27° C (data from Kaye and Laby, 1986).

Table 2. Hearing range (frequency or pitch of sound) for a variety of animals (Fay & Popper, 1994).

Species	Lower end/Hz	Upper end/Hz
Human	64	23,000
Dog	67	45,000
Elephant	16	12,000
Bat	2,000	110,000
Beluga whale	1,000	123,000

for eco-location, i.e. they use sound to navigate. Beluga whales can hear sounds from many hundreds of miles away, since sound travels more efficiently in water.

The loudness of sound is measured using the decibel (dB) scale, with sounds above 85 dB thought to be harmful to humans. Leaves rustle at around 30 dB, heavy traffic is around 80-90 dB, an elephant's trumpeting is around 117 dB and a bat is up to 140 dB (but can often not be heard by humans, being above our high frequency range). The loudest animal on Earth is the Blue whale at 230 dB (Fay & Popper, 1994).

Ways of using sound sensors in investigations

In primary schools, the loudness of sound can be measured using a sound sensor, data logger or sound app. In a previous article, we described the use of data loggers that measured sound levels (loudness) and how these could be used on a sound trail (Morgan, 2016; Morgan *et al*, 2017), utilising the benefits of learning outdoors (Grimshaw *et al*, 2019). A sound sensor is inexpensive, and children can calibrate it themselves; they do not need to understand the decibel scale, but can generate a sound from a range of sources and see what loudness level is recorded by the sensor. Use of sound sensors can give rise to open-ended investigations, with children investigating how sound levels change around their school grounds. Sound levels can easily be measured over a period of time, allowing the children to analyse changes over time and interpret why these changes occur. A sound sensor could be left in a 'secret position' in the school for a day, with children then asked to interpret the line graph produced and discuss where the sensor could have been left.

Hearing air pollution?

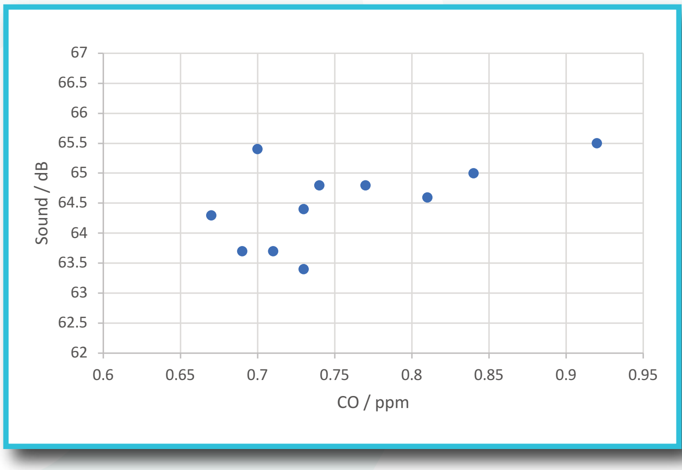
There is no doubt that air pollution is a serious problem in terms of health, particularly in cities (e.g. Harrison *et al*, 2020a, 2020b) and that key pollutants such as carbon monoxide (CO) and small particles such as PM_{10} can be measured using a range of pollution sensors, including hand-held ones. These sensors are becoming cheaper, and some reliable ones that can be used in schools exist, but data interpretation is not straightforward. A data reading from a pollution sensor, assuming that it is calibrated properly, can be almost meaningless because of its complexity. So how can a sound sensor help to measure pollution? We argue in this article that pollution sources such as vehicles, construction, etc. generate noise and so there is the potential that a sound sensor may work as a proxy for measuring air pollution. Several studies have shown that there is a correlation between air pollutants and noise levels in urban settings, since sources of pollution such as vehicles also generate noise (e.g. Kim *et al*, 2012; Shu *et al*, 2014). For this study, we used a carbon monoxide sensor and a sound sensor to explore their potential use in different investigations around school, with a mix of children from Key Stage 2 (aged 7-11). Three investigations are described below, with examples of data presented in Figures 1-3.

Fixed sensor

Figure 1 shows an example of data from two sensors co-located at a fixed location (~ 1.5 m from the ground attached to the perimeter railings) near the entrance to school, around the time of the children arriving at school in the morning. There is some correlation between the CO and sound levels; typically, there is not a perfect correlation but a consistent positive one, i.e. as CO increases, sound levels increase.

Data were collected over a number of days, with similar findings suggesting that the sound sensor could be used as a proxy for measuring pollution. In addition, counting the number of vehicles and the sound levels gave a good correlation, i.e. more vehicles corresponded with louder sound sensor data. Therefore, we argue that the sound sensor alone could be used as a proxy for measuring pollution and the number of vehicles arriving at the school. If schools are trying to monitor and manage vehicle numbers and their impact in and around the school environs (e.g. at the start and the end of the day), then a sound sensor is a cheap, easy-to-interpret way to gather data. However, there are times when the sound sensor will give elevated levels when pollution levels can be lower, e.g. during heavy rainfall or when children (and adults) shout near the sensor (though this causes a short-lived signal), and so careful thought to the location is needed and some trialling of location is recommended, together with perhaps keeping a weather log.

Figure 1. CO and sound data collected in a fixed position as the school drop-off begins.



Around the school grounds or outer perimeter

Figure 2 shows an example of CO and sound levels when walking around the outside of a school grounds during the morning when the children are being dropped off. Data collected show a similar general trend to above, in that elevated sound levels correlate with elevated levels of CO (apart from in situations such as heavy rainfall or children talking into the sound sensor).

The change in sound levels between busy roads and roads where there is much less traffic is consistent. It is possible to generate sound maps around the school and further afield to suggest walking or cycling routes to school that have lower levels of pollution (quieter routes).

Figure 2. CO and sound levels during a walk around the school perimeter.

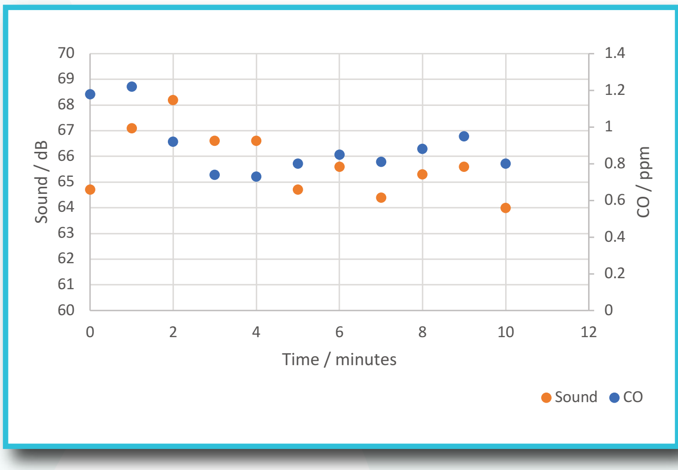
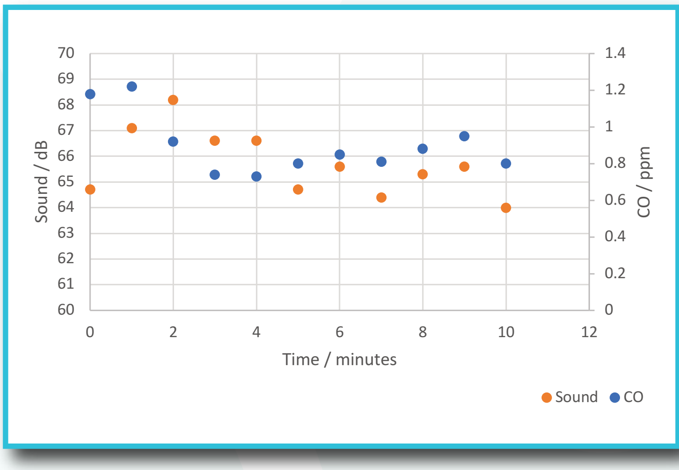


Figure 3. CO and sound levels during a circular walk from the school and back to the school.



Interesting data on walks from school and back again

Figure 3 shows a walk from the school, around a route and back to the school. Other walks show correlations like those seen in Figure 2, but some were similar to those in Figure 3. These more unusual findings could provoke discussion: what was happening between ca. 5-10 minutes from the start of the walk? The walk followed a route through a park during this time and the level of pollution, as measured by the CO sensor, dropped, but the sound levels went up. On most occasions, the sound level dropped too, but sometimes the children on the walk became excited and started making a lot of noise. In Figure 3, the increase in sound levels was due to natural sounds such as birds chirping, dogs barking, etc. and so using the sound sensor as a proxy here would suggest that pollution levels went up. However, by taking notes on the walk, it is possible to resolve the differences. Comparing the CO sensor with the sound sensor consistently showed that pollution and sound levels were lower in parks and similar areas away from main roads, and so routes through these environments can be assumed to be cleaner than those along main roads. This has been verified many times in the literature (e.g. Kaur *et al*, 2007). Studies show that both air and sound pollution levels drop in green spaces (Gozalo *et al*, 2018; Bunds *et al*, 2019; Xing & Brimblecombe, 2020).

Future developments

The sound sensor used in this study measured loudness but, if future sensors also measure the frequency or groups of frequencies of the sound, this would help the user to distinguish between vehicles such as cars (estimated to be 100-600 Hz) and trains (30-200 Hz), and natural sounds such as dogs barking (1000-2000 Hz) or birds chirping (1000-8000 Hz); i.e. human-induced sounds tend be at a lower frequency than natural ones (that we might encounter in the UK). Therefore, in addition to measuring the loudness, measuring frequency could help to make a sound sensor even more useful.

Summary

It has been noted that both air and noise pollution can affect health, especially that of children (Gupta *et al*, 2018). Studies on journeys through urban environments show strong correlations between various air pollutants and noise levels (e.g. Engel *et al*, 2018). A sound sensor can be used as a proxy for measuring air pollution levels around a school in an urban setting and its environs, although this may be less useful in rural settings. Sound sensor positioning and non-traffic sources of sound (e.g. children and rain) will need to be considered. Determining 'clean' routes to school, i.e. quieter ones, can reduce air pollution exposure. In the future, it is envisaged that clean electric vehicles will replace the fossil fuel-generated ones, noise levels will drop (Pardo-Ferreira *et al*, 2020) during this transition and so a sound sensor could be a useful sensor with which to investigate this transition.

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