An inexpensive particle monitor for smoker behaviour modification in homes

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ABSTRACT

Objective To compare the response of a new particle counting instrument (Dylos DC1700) with that produced by a device (TSI Sidepak Personal Aerosol Monitor AM510) commonly used to measure \( \text{PM}_{2.5} \) in settings where secondhand smoke (SHS) is encountered.

Methods Controlled chamber experiments with different SHS concentrations were generated by burning a cigarette for varying time periods and running both devices simultaneously.

Results The Dylos and Sidepak devices produced similar responses to changes in SHS concentrations up to 1000 \( \mu \text{g/m}^3 \). Using 591 min of contemporaneous measurements from 13 chamber experiments, an equation was developed to allow conversion of particle number concentration data from the Dylos to estimated mass concentration data for SHS aerosol.

Conclusions The Dylos DC1700 can provide real-time data that may be converted to an estimate of SHS levels in smoky environments. Given the low cost, low noise and simplicity of use, this device is likely to be a useful tool for interventions to provide feedback of SHS concentrations to help motivate changes in smoking behaviour at home.

INTRODUCTION

Secondhand smoke (SHS) exposure is linked to a range of respiratory and cardiovascular conditions.1,2 Smoke-free legislation has been introduced in many countries to limit SHS exposure resulting in large reductions in both workplace and social settings.3 While there is no evidence that displacement of smoking to homes has occurred as a result of smoke-free legislations,4 non-smokers who live with smokers still have high SHS exposures.5 Methods of encouraging smokers to make their home and car settings smoke-free have been the subject of many previous studies (eg, references6,7).

In the occupational setting, there is evidence that provision of real-time exposure data about hazardous chemicals can lead to behaviour modification to reduce exposure.8 Our group has been exploring this personalised exposure feedback concept in a pilot study called REFRESH (Reducing families’ exposure to second-hand smoke in the home) where real-time data on SHS concentrations are used to demonstrate to mothers of young children the impact their smoking behaviour has on air quality within their own home.9,10 The results of this trial support the use of personalised feedback as a motivational tool and suggest the methodology should be rolled out on a wider scale.

For the REFRESH trial, the Sidepak AM510 Personal Aerosol Monitor (TSI Inc, Shoreview, Minnesota, USA) was used to measure and log concentrations of particulate matter less than 2.5 microns in diameter (PM\(_{2.5}\)). This device has been used successfully across many previous studies of SHS exposure.8,11,12 There are, however, three issues with the Sidepak that we have identified in our time using this device: cost, noise and ease of use.

At current prices, the Sidepak costs approximately £2600 ($4100). In large-scale or public-health interventions where many devices are required or there is the possibility of devices being lost, stolen or damaged, this cost may be seen as a barrier to use. The second issue is the noise produced by the device’s internal pump. The instrument was designed for use in occupational settings where the low hum is unlikely to present a problem. In the quieter conditions found within a home this can be more problematic. The third issue relates to the ease of use. Its complex menu selections may place too high a burden on study participants in expecting them to set it up correctly, resulting in lost or invalid data. To date, all our work has used a trained researcher to set up the Sidepak within the home setting.

In our search for an instrument that addressed these issues we identified the Dylos DC1700 (Dylos Corporation, Riverside, California, USA). The Dylos is a similar light-scattering device that is marketed to householders as an instrument that can be used to determine how clean the air is within a home. It has a current price of £270 ($425), just over 10% of the cost of the Sidepak, is potentially quieter than the Sidepak due to the use of a small fan and larger air inlet, and appears to be simpler to install and activate to logging mode with a single press of one button. The device, however, provides particle counts expressed per 0.01 cubic foot (0.283 litre) of air and the manufacturer provides no method of converting this to a mass concentration as produced by the Sidepak.

This paper describes the work we have carried out to determine the performance of the Dylos DC1700 in measuring SHS concentrations in comparison with the data produced by a Sidepak AM510 within controlled laboratory conditions.

METHODS

Instruments

Dylos 1700: this instrument uses a laser light scattering technique to measure the number of particles in two particle size ranges, >0.5 and >2.5 \( \mu \text{m} \). All data presented in this paper relate to the >0.5 \( \mu \text{m} \) size range. The instrument draws air through an inlet (4×6 cm) in the casing of the device using a small fan. The Dylos logs the number of particles every minute and is capable of reducing exposure.8 Our group has been exploring this...
logging 10 000 data points. The device is supplied with proprietary software Dylos Logger (V1.60) to enable the logged data from the instrument to be downloaded. Particle counts are expressed as a concentration per 0.01 cu ft of sampled air with the upper limit of the device memory 65 536 particle counts per 0.01 cu ft (0.283 l).

TSI Sidepak AM510: this device draws air through an impactor (the size-selective PM2.5 impactor was used in all our experiments) using a pump set at 1.7 l/min, and uses a laser light scattering technique to quantify airborne concentrations of particulate matter. The device can log recorded values every minute expressing the output in mg/m³ with a sensitivity down to 0.001 mg/m³. The maximum concentration the Sidepak records is 20 mg/m³. The device is factory calibrated to Arizona Test Dust but can be internally calibrated for the characteristics of any type of aerosol. Previous studies measuring SHS aerosol have used a calibration factor of 0.2955.13 and this factor was applied to all data collected using the Sidepak device. At the start of each sampling day the Sidepak was zero calibrated using the manufacturer supplied High-Efficiency Particulate Air filter and had clean grease applied to the impactor. Logged data were downloaded using the TSI TrackPro software (V4.4.0.5).

Chamber tests
Various concentrations of SHS were generated by lighting a commonly available commercial cigarette (King Size, Benson and Hedges Silver) and allowing it to burn for a variable amount of time in a sealed exposure chamber (volume: 3.63 m³). This chamber was fitted with an extraction fan which was used to remove the SHS aerosol at the end of each experiment.

Both instruments were set to log every minute for the duration of each chamber test. A total of 14 experiments were performed, each for a period of about 30–60 min, including 5 min prior to lighting the cigarette and 5 min at the end when the extraction system was activated to return the chamber air to a ‘steady-state’ state. The duration of cigarette burning was typically less than 1 min with the concentration of PM2.5 reaching a steady-state within 1–2 min after the completion of the cigarette burning. Due to the small volume of the chamber, the lack of air flow into and out of the chamber, and the low settling velocity of SHS aerosol, the concentrations of PM2.5 remained relatively stable over the logging period.

Statistical analysis
The data were downloaded from both instruments and exported to Microsoft Excel 2007 for analysis. Average values for the duration of the chamber experiments were calculated from the time of lighting the cigarette to the time the extraction system was switched on.

RESULTS
The average duration of the 14 chamber experiments was 46 min (range 37–65) with the average duration of the ‘steady-state’ SHS burning time (from cigarette lighting to initiation of the extract ventilation) being 52 (range 22–36) min. One of the chamber experiments produced an average concentration of PM2.5 (as measured by the Sidepak) that was approximately 3 mg/m³. At these concentrations, the particle number levels recorded by the Dylos exceeded the 65 536 (16 bit) per 0.01 cu ft logging capabilities of the device. The results from this test and for five other 1 min data points where the Sidepak concentration was >1000 μg/m³ were excluded from further analysis. Average PM2.5 values, as indicated from the Sidepak, of the 13 remaining chamber tests ranged from 27 to 650 μg/m³.

Figure 1 shows these contemporaneous Dylos and Sidepak 1 min data (n=591) from all 13 chamber experiments. A second order polynomial was used to find the best fit curve between these data points (equation 1) giving an R² value of 0.90:

\[ y = 2 \times 10^{-7} x^2 + 0.0049 x + 11.7 \quad (1) \]

where x is the number of particles counted by the Dylos 1700 (per 0.01 cu ft) and y is the adjusted measurement of PM2.5 mass (μg/m³) from the Sidepak with a calibration factor of 0.295 applied.

A small number of points from the chamber experiments (n=6) appear to be outliers. Examination of the timing of these points indicates that they appear to be 1–2 min values around the time of cigarette lighting.

DISCUSSION
This is the first study to assess the viability of the Dylos 1700 instrument for use in studies to estimate exposure to SHS. From a number of controlled chamber experiments we developed an equation that can be used to broadly predict particle mass concentrations across the range of SHS levels likely to be encountered in home settings. The Dylos instrument provides the user with the ability to collect real-time data to use in feedback or educational style interventions to encourage smokers to modify their behaviour in much the same way as has been reported previously using the Sidepak device9,10 but for a fraction of the cost.

One of the challenges of using measurements of SHS in any microenvironment such as the home or workplace is the need to communicate the concentrations measured in a meaningful way. Much of the recent work on SHS exposure assessment has used PM2.5 as measured by the TSI Sidepak device. In these studies, the PM2.5 concentrations produced have tended to be compared or explained relative to health-based outdoor air quality guidance produced by either the US Environmental Protection Agency (US EPA)14 or WHO value that is now also deemed to be applicable to indoor settings.15 Given that there is almost no epidemiological evidence linking particle number concentrations with health effects, and in order to be able to
use any new instrument to communicate the risks of poor indoor air quality to smokers, there was a need to determine the relationship between the particle number concentrations as reported by the Dylos and the mass concentrations from the Sidepak. Our results provide a useful equation for estimating SHS mass concentrations from the particle numbers generated by the Dylos.

There are a number of weaknesses in our work. First, nearly all freshly dispersed SHS particle mass lies in the diameter range of 0.02–2 μm with a mass median diameter of 0.2 μm. Consequently, both devices used here are limited in terms of the fraction of SHS particulate they can detect, although the Dylos is limited to a greater degree (0.5 μm lower limit of Dylos compared with 0.1 μm for Sidepak). Second, the chamber work presented here used an aerosol of only sidestream smoke from the tip of burning cigarettes and did not mimic actual smoking conditions where both sidestream and mainstream smoke are produced. There are likely to be some differences in these two components with one study suggesting that sidestream smoke has a median diameter of about a third of that of mainstream smoke.

We also note that we have only compared the output from the Dylos with an alternative secondary method, the Sidepak, rather than gold-standard, gravimetric or filter-based methods. Both devices used in this paper are light-scattering instruments and, as such, are not specifically designed to provide accurate mass concentration data. The Sidepak has been extensively used in the scientific literature to provide an approximation of SHS concentrations, with calibration experiments providing methods of adjusting the value reported by the instrument to realistic mass concentrations. We have used the relationship between the Sidepak and the Dylos established in our chamber experiments to further extend this logic to the Dylos, but we caution against the assumption that photometric devices provide accurate mass concentration data. We do, however, believe that the Dylos can be used as a valuable educational tool in providing an approximation of mass concentration values and providing smokers and those involved in tobacco control with a means of comparing the result of changes in legislation, smoking activity or other measures.

Our work suggests there are several limitations of the Dylos DC1700. The first being that it has a non-linear response becoming less responsive to increases in PM levels when concentrations increase. We have been able to manage this by fitting a second order polynomial to the experimental data and this provides a strong fit with an R² of 0.90. Second, we note that the Dylos does not directly present particle number data for the size fraction <2.5 μm with the main output being particles >0.5 μm in size (with no upper bound). Indirectly, there is a mechanism for providing particle number concentrations in the size range of 0.5–2.5 μm by subtracting the values provided for the size range >2.5 μm from the ‘all particles’ (>0.5 μm) data. We did not do this in our chamber experiments due to the fact that there were very small numbers of particles in the >2.5 μm range generated by the SHS aerosol. Third, the device, as it is currently designed, returns erroneous readings when the particle number concentrations exceed 65,536 particles per 0.01 cu ft which is the 16-bit limit of the memory logging facility. This is likely to occur at concentrations of greater than 1000 μg/m³ for SHS aerosol. Currently, the device returns a false value by returning to zero and recording the counts above the 65,536 figure. These data need to be marked as ‘overflow’ values within the logging memory in order to prevent inconsistent values being produced.

We also acknowledge that we have only tested a single Dylos DC1700 unit and we do not know how consistent the devices are, particularly in terms of the flow rate generated by the small internal fan system. There is a need to test agreement between different units and to determine if, and how, the instrument’s response changes over time with use. The tobacco control and measurement communities need to undertake further validation and testing of this instrument to determine how it performs in real-world settings.

CONCLUSIONS
Our interest in the Dylos DC1700 stemmed from our need to find an instrument that delivered similar performance characteristics to the Sidepak at a lower unit cost while producing less noise in home settings. From the results of these first tests we believe that the Dylos DC1700 provides public health and tobacco control professionals with cheap, real-time, fine-particle concentration data that can be converted to give approximate mass concentration values and used to communicate information to smokers about their household air quality relative to appropriate health-based air quality guidance. This information may be a powerful motivator to affect change in smoking behaviours.

What this paper adds

- This study identifies a new instrument capable of being used by the tobacco control community to feed back information on secondhand smoke (SHS) concentrations in smokers’ homes.
- By applying a non-linear equation to the data from this particle counting instrument, it was possible to obtain estimates closely associated with a well-used method for SHS assessment.
- Advantages include quieter operation, simpler set up and much lower cost.

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REFERENCES


