Facilitating occupational noise management: The use of a smartphone app as a noise exposure, risk management tool

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Abstract:

With the arrival of the modern smartphone, a pocket-sized computer was introduced for every-day use and applications rapidly developed for uses other than straightforward telephone calls. The purpose of applications (apps) range from gaming to scientific. With the inclusion of an inbuilt microphone use as a sound level meter was inevitable. By including a time measurement, use is easily extended into personal noise dosimetry. But how practical and useful is a smartphone app as a dosimeter? The National Acoustic Laboratories addressed this in a practical way by developing a noise dosimeter app. This paper focusses on establishing the app utility by verifying noise level and dosimetry results for precision and accuracy, and for use in occupational noise management and as a hearing health education tool.

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Introduction

Contemporary Workplace Health and Safety (WHS) is based on a risk management, consultative principle as opposed to the traditional prescriptive approach where definite courses of action were required (The Cabinet Office: 1997; WorkCover: 2001; Safe Work Australia: 2009). The intent is to encourage an appropriate degree of participation from all of those who have contact with the workplace. One of the goals for the National Acoustic Laboratories (NAL) is to decrease hearing loss in the workplace due to noise. One possible method of engaging individuals in hearing loss prevention programmes is through the use of personal noise dosimetry via the use of a simple smartphone noise exposure app.

Following an examination of the numerous sound level meter smartphone apps currently available, NAL personnel decided to develop their own app. This decision was made in lieu of undertaking a review and evaluation of existing apps, as many others have done previously (Keene et al: 2013; Kardous & Shaw: 2014; Nast et al: 2014; Staab: 2016). NAL was particularly interested in developing an app as a research and educational tool. It was considered practical to develop a combined sound level meter (SLM) and personal sound exposure meter (PSEM)/dosimeter app for which requirements and procedures are described in Australian Standards and various codes of practice (Standards Australia: 2005 ; NOHSC 2000).

Methodology

Platform selection

The first task was to choose an appropriate platform on which to develop the tool. An informal review of smartphones available (n = 13) revealed an almost equal mix of both Android and iPhone (Apple®) based devices.

A practical discrimination task was designed where the comparative performance of the respective microphones mounted within the devices could be undertaken. On each of the devices a white noise recording was made using the recording application 'PCM Recorder Lite'. This application has identical Android and Apple® versions. The recorded output RMS voltage levels were then compared from their respective WAV files for precision and consistency. At this stage 'trueness' was not considered as this could be accounted for through a future calibration process.

The Apple® devices were found to match the criteria with much less variation than the Android devices (see Figure 1 below). The Apple® devices were consequently adopted for the development platform.

Platform development

The software for the SLM/dosimeter App was developed by proceeding through a number of iterative development stages of test and re-test before the formal verification.

Laboratory verification

For the initial tests the App was installed on an iPhone 5 (OS 7.1.1) in a laboratory setting with low background noise ($L_{Aeq} < 30$ dB) and positioned about one meter in front of Tannoy V8 loud speaker. Testing consisted of the comparison of the indicated output level (L_{Aeq}) on the iPhone to an adjacent, calibrated, precision, integrating SLM, B&K model 2250 SLM, in accordance with IEC61672-1:2013 Class 1 requirements. The measured L_{Aeq} on the App and the B&K 2250 SLM over a range of 40 to 120 dB for a 1 kHz pure tone sine wave signal and a 'pink' noise were assessed. In addition, because human speech is predominantly around 4 kHz and is therefore considered to be an important area, of the acoustic spectrum, the response of the App microphone in relation to a 4 kHz sine wave was assessed.

Field verification

Field testing aimed to directly compare measurements made in numerous workplaces and other noisy locations. Relatively short duration, task sampling measurements (up to about 30 min) were made using a SLM while long duration measurements (up to around eight hours) were carried out with a PSEM or dosimeter. The SLM measured loudness (L_{Aeq}) was used in conjunction with the exposure time to calculate noise exposure ($L_{Aeq,8h}$) while the PSEMs present both loudness and exposure. For WHS purposes both methods are equally valid.

Seventy-two (72) measurements were made at a wide variety of locations including: underground and open cut mining operations in New South Wales, Queensland and the Northern Territory; train stations, bus stops, busy intersections; shops, restaurants, cafes, libraries and offices. Specific noisy tasks such as use of machinery and power tools were also assessed.

All measurements were carried out with the iPhone microphone in as close proximity as possible and oriented similarly to the SLM or dosimeter microphone as required by the combined Australian/New Zealand Standard (Standards Australia: 2005).

Results

Verification in the laboratory

Figure 1 shows the distribution of the relative magnitude of the output signal WAV files recorded on the sampled smartphones. The seven Apple® iPhones tested, Model 4 (n = 2) and Model 5 (n = 5), provided greater consistency of results compared to the six Android counterparts tested (one each of: HTC Desire; Samsung S3; Google Nexus S; Samsung GT-19100T; Samsung Google Nexus; and Sony Xperia). Important features of good measurements are accuracy and trueness. The better grouping of the Apple® device microphones demonstrates they have a consistent performance and repeatability between microphones, implying better accuracy. The second feature, trueness, can be accounted for during a calibration process.

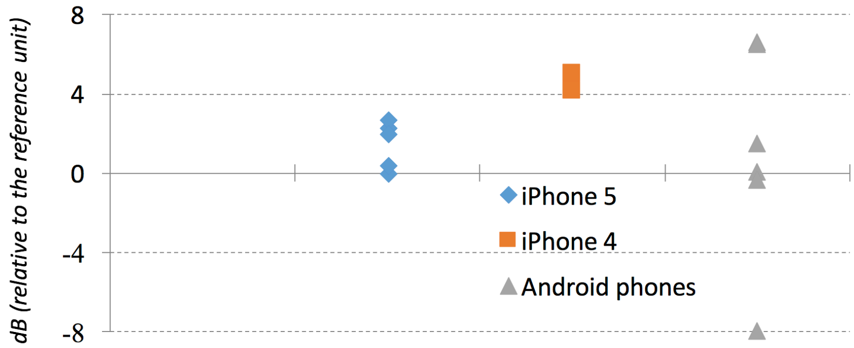

Figure 1: Comparative distribution of WAV file output L_{Aeq} for various smartphone platforms [iPhone 4 (2); iPhone (5); and one each of HTC Desire, Samsung S3, Google Nexus S, Samsung GT19100T, Samsung Google Nexus, and Sony Xperia].

Figure 2 compares the measured LAeq on the App and the B&K 2250 SLM over a range of 40 to 120 dB for a 1 kHz pure tone sine wave signal. The curve of 'best fit' shows there is a linear relationship between the B&K 2250 SLM and the App response (R2 = 0.99).

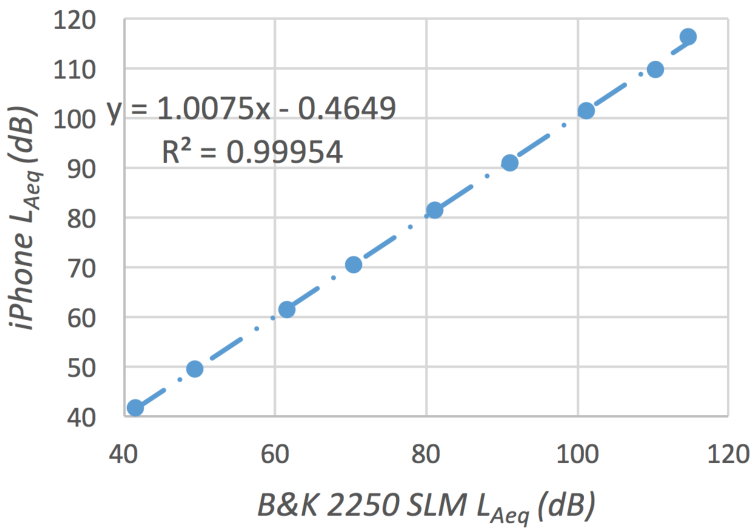

Figure 2: Relation of LAeq measured on App compared to B&K 2250 for a 1 kHz sine wave over the range 40 to 120 dB.

The assessment of the response of the App microphone in relation to a 4 kHz sine wave found a satisfactory linear correlation over the main range of interest of 80 to 120 dB (R^2 = 0.98) as presented in Figure 3.

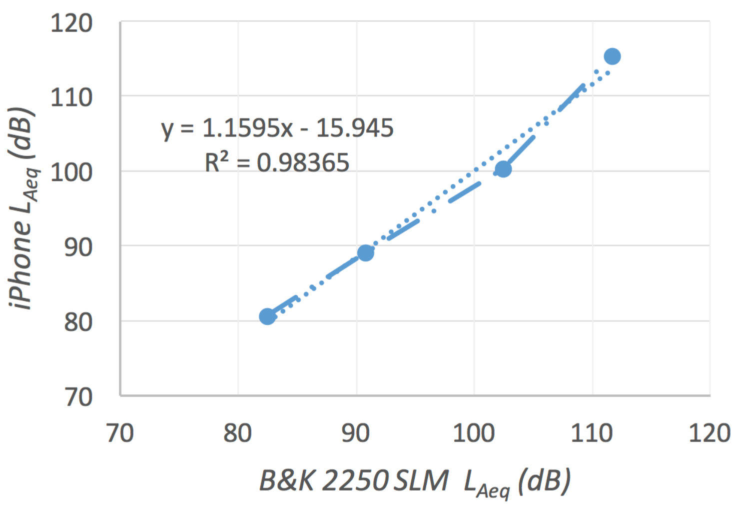

Figure 3: Relation of LAeq measured on App compared to B&K 2250 for a 4 kHz sine wave over the range 80 to 120 dB.

Figure 4 compares LAeq results for the pink noise test signal. Again there is a satisfactory correlation of R2 = 1 over the range 40 to 120 dB.

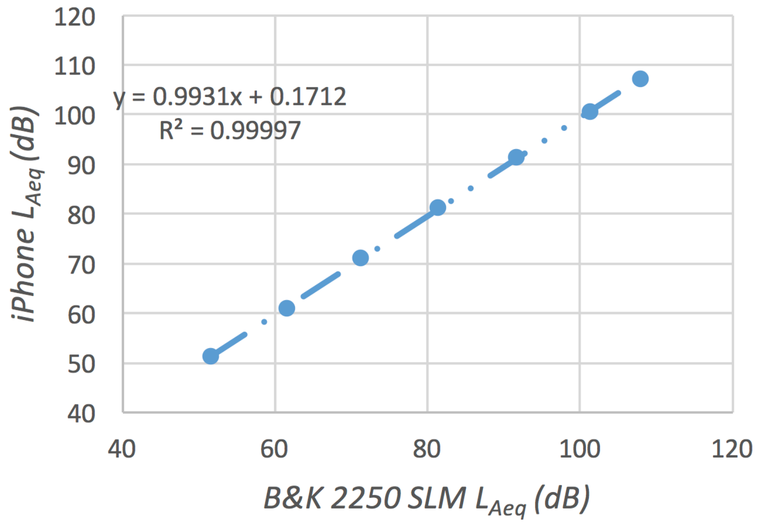

Figure 4: Relation of LAeq measured on App compared to B&K 2250 for a pink noise signal over the range 40 to 120 dB.

Verification in the field

The 72 field measurements of L_{Aeq} taken from the App output are compared to the combined results from the B&K 2250 SLM used for short time sample measurements and two CEL, model 350 and 35X, dosimeters used for the longer term, dosimetry measurements. The resulting correlation is good at $R^2 = 0.97$.

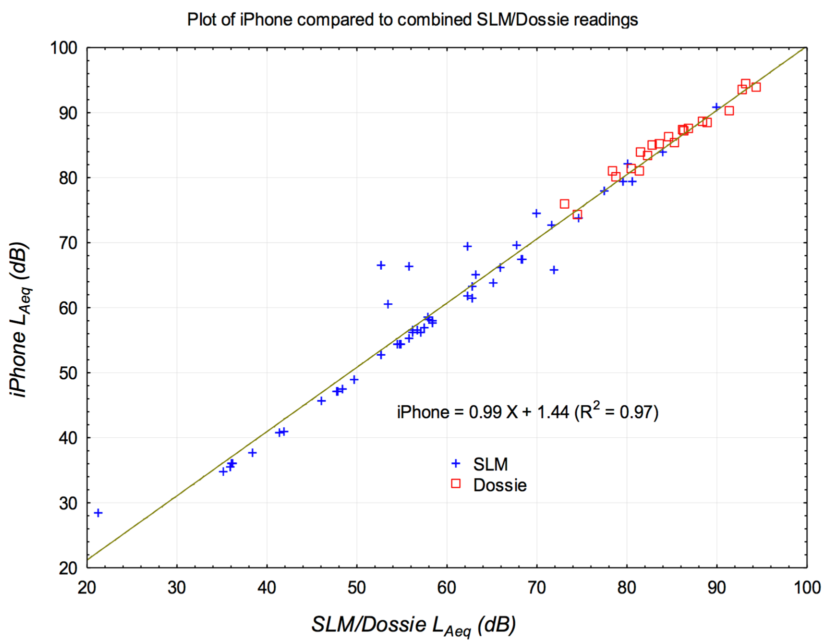

Figure 5: Comparison of field LAeq measurements from App and a combination of B&K 2250 and CEL model 350 and 35X dosimeters from 20 to 100 dB.

A detailed examination of the ‘outlying’ data points was undertaken to find reasons for their departure from the line of best fit. The low LAeq data point (21.3, 28.3) was taken in a low noise, anechoic room where the Apple® microphone would not normally be expected to operate because its primary function is to operate at or above conversation voice levels. Other measurements in the 60 to 70 dB range lying away from the line were taken in locations such as external balconies on buildings, walkways, in railway stations, and in the vicinity of road traffic where there was wind noise affecting the microphone performance. This is reflected in the direction of the outliers above the line of best fit (ie higher noise levels). The SLM/CEL microphones were protected by a microphone wind-shield as routine best practice while the smartphone microphone was unprotected. Overall the correlation is good notwithstanding the inclusion of the outliers.

Figure 6 presents results for LCpeak (C-weighted peak noise level) measurements between the combined results from the B&K 2250 SLM and two CEL model 350 and 35X dosimeters and the equivalent iPhone results. The Apple® microphone appears to exhibit a saturation effect at high peak levels, as demonstrated by a second degree curve of best fit (R2 = 0.91). The microphones used in smartphones are not designed to respond accurately to high level impulse noise.

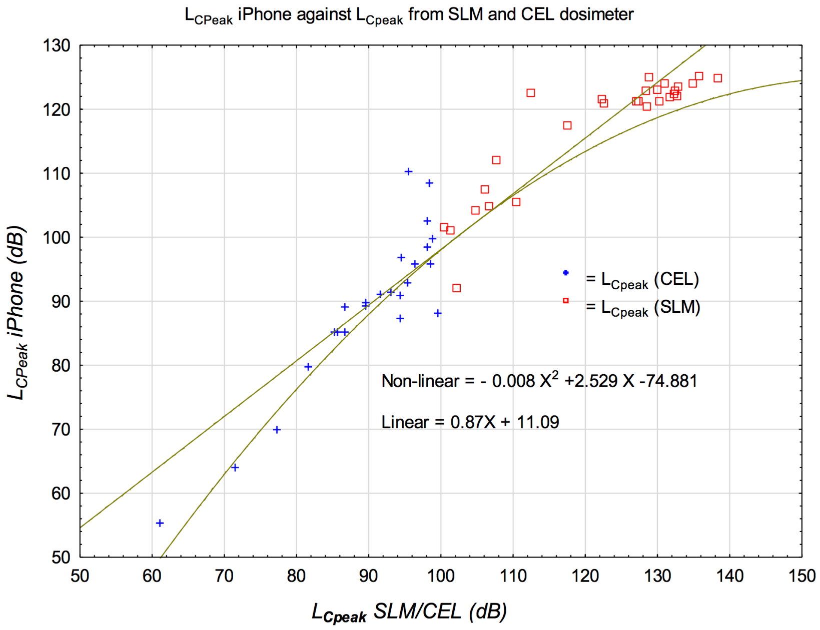

Figure 6: Comparison of field LCpeak measurements from App and a combination of B&K 2250 and CEL model 350 and 35X dosimeters from 50 to 150 dB.

A closer examination of peak measurement responses has not been conducted given that the aim is to produce an App suitable for assessment of exposure to continuous noise. Peak values must be considered unreliable and indicative only.

The App visual output is illustrated by the ‘screen shots’ presented in Figure 7. The output provides the measurement start time, in real (local) time, and sample duration. A graph provides a series of one minute LAeq values for the entire recording period. Values greater than or equal to 85 dB are red in colour and black if less than 85 dB. Included are the maximum peak value (LCpeak) measured over the whole sampling period and the calculated exposure LAeq,8h in dB and in Pascal squared hours (Pa2h). Also included is what is referred to as a “Safe exposure time estimate” under the assumption that this was a measurement of the typical projected exposure. Geographical co-ordinates and a map for the location of the measurement site are included as a display option. If the measurement site is mobile or the measurement was taken over several locations, the location information is that of the last one minute measurement interval. Options are also available for measurement details and any appropriate comments.

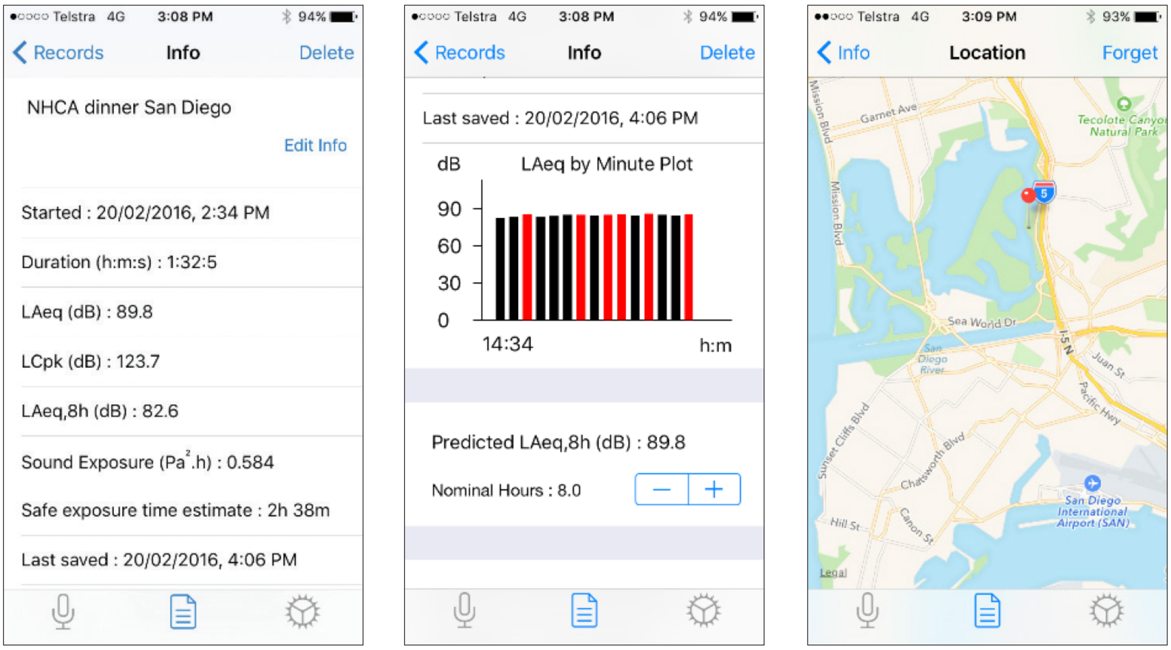

Figure 7: Typical App output, measurements, graph and location.

Discussion

Under laboratory conditions with continuous noise there is excellent agreement between measurements taken with the App and those carried out in parallel with a Class 1 integrating SLM and dosimeters. For some field measurements the discrepancies occurred when wind noise caused disturbance to the microphone. Smartphone platforms are not normally required to operate precisely under these conditions without a wind-screen as is normal practice with an SLM or dosimeter.

A comparison of the consistency of the LAeq results was carried out using a Student t-test. The results can be summarised as: i) SLM results compared to app results, $p = 0.102$; ii) Dosimeter results compared to app results, $p = 0.002$; and iii) combined SLM/Dosimeter results compared to app results, $p = 0.026$. These are as would be expected in that the results taken with the SLM compared to the NAL app was better when compared to the Dosimeter results while the overall comparison of the combined was within a 95% confidence interval ($p = 0.026$). Implying that the better the instrument used, the better the results.

For impulse noise measurement, the results show obvious limitations in the performance of the App. Smartphone microphones are not expected to be able to accommodate sudden transients during normal use. In fact it is possible that smartphone hardware/software combinations may be specifically designed to smooth out such peaks and irregularities. As a general comment, using dosimeters for measuring peak results can be uncertain because inadvertent bumping or deliberate interference with the microphone can occur with an unattended instrument. Occupational hygienists and others using dosimetry will regularly check peak noise levels with an SLM. However, the correlation ($R^2 = 0.94$) with the measurement microphone appears reasonable until a saturation effect begins above around 110 dB. The App was intended to monitor continuous noise so this is not a significant limitation to its use.

As a noise exposure risk management tool, by supplying noise level (LAeq) in dB, exposure in both dB (LAeq,8h) and in a linear measure (EA,T) of Pa^2h, the App provides sufficient information for the user to judge the relative level of risk. It is indeed fortunate that the accepted daily Exposure Standard of 85 dB LAeq,8h is 1.01 Pa^2h. Thus EA,T is easily interpreted as a level of 1 Pa^2h being ‘acceptable’ for daily exposure to within 1% accuracy. An exposure greater than 1 Pa^2h can be interpreted as unacceptable and thus preventative action is required. The App provides an estimate of the recommended exposure time required to remain at less than the Standard on the assumption that the nature of future exposure does not significantly change.

Limitations

There are obvious limitations in the use of this App as a direct replacement for those instruments required by the regulations in various WHS jurisdictions. The use of a smartphone noise measurement app is not a direct replacement for a ‘detailed assessment’ as required by paragraph 6.1.3 of combined “Australian/New Zealand Standard (2005) AS/NZS 1269.1 Occupational noise management, Part 1: measurement and assessment of noise immission and exposure” (Standards Australia 2005. However, within a regime where WHS is structured toward risk management, access to a self-assessment tool on a device that people have at their disposal is a reasonable approach. The concept is to actively engage individuals in the process of looking after their hearing health. The use of a smartphone monitoring App offers a tool of exceptional convenience for noise exposure risk management and assessment. It is a true 'personal' noise exposure meter and use can not only assist with the management of noise exposure but also function as an awareness raising tool.

Microphone positioning is often difficult in an active workplace and particularly so where personal dosimetry is undertaken. However, it should be kept in mind that the aim of this was not dosimetry per se but rather the comparison of dosimetry results from different measurement instruments. While the positioning of the microphone location met the Standard requirements as far as practicable, the microphones on the iPhone and the dosimeter and the SLM respectively were always co-located.

While accurate measurement is desirable more relevant, is that this SoundLog App provides non-technical persons access to a simple means of assessing noise exposure risk without having to resort to specialist assistance. In small businesses the effort and cost of accessing professional WHS services is a significant deterrent. For small businesses and the individual who may be aware that exposure to loud noise may poses a risk to future hearing health the App functions as an awareness raising and discrete assessment tool.

Conclusion

For general and preliminary assessments, as described by the Australian/New Zealand Standard (Standards Australia: 2005), the App does should be able to perform as a satisfactory assessment tool within the acceptable limits of accuracy of risk management practice as applicable for WHS. While it cannot replace a detailed assessment (Standards Australia: 2005) it can act as a personal exposure assessment tool and as an educational and awareness raising opportunity. The App is equally applicable in the workplace or during leisure activities.

Acknowledgements

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