Exploring the accuracy of smartphone applications for measuring environmental noise

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This paper reports on experimental tests undertaken to assess the capability of noise monitoring apps on smartphones to be utilised as an alternative low cost solution to traditional noise monitoring using a sound level meter. The methodology consisted of testing more than 100 smartphones in a reverberation room. White noise was utilised to test the ability of smartphones to measure noise at background, 50, 70 and 90 dB(A) and these measurements were compared with true noise levels acquired via a calibrated sound level meter. Tests were conducted on phones using the Android and iOS platforms. For each smartphone, tests were completed separately for three leading noise monitoring apps culminating in more than 1400 tests. The results suggest that apps written for the iOS platform are superior to those running on the Android platform which, in relative terms, performed rather poorly. For one of the iOS noise apps, the test results were within 1 dB(A) of the true noise level indicating the clear potential of the iPhone to be used as a low cost monitoring device in the future. The research has implications for the future use of smartphones as low cost monitoring and assessment devices for environmental noise.

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1 INTRODUCTION

The development of smartphone technology and its impact on environmental noise studies has only recently begun to receive some attention in the academic literature. There are some studies which suggest that smartphones are capable of replacing traditional noise assessment devices such as sound level meters (SLMs) in the not too distant future. Kanjo has outlined the possibility of developing a mobile phone platform for measuring noise in cities and highlights the potential of such avenues for the future[1]. Similarly, D'Hondt et al have demonstrated the possibility of smartphone-based noise apps to be utilised by ordinary citizens as a form of crowd sourced participatory noise assessment in cities[2]. Studies such as these suggest that the future of noise assessment, whether it is in cities or elsewhere, will likely be tied closely to developments in smartphone and other forms of innovative mobile technology that are easily and relatively affordably accessed by ordinary citizens, especially in developed nations.

There are only a small number of studies which have investigated issues that are relevant to the current research. Perhaps the most relevant is a recent study by Kardous and Shaw[3]. They tested the accuracy of 10 iOS and 4 Android apps for measuring noise in occupational settings on 8 smartphones and one tablet. Their research found that the iOS noise app – Sound Meter, developed by Faber Acoustical – has the best agreement in A-weighted sound levels (-0.52) with reference values while three other apps for the iOS were within +- 2dBA of reference values. This led the authors to conclude that devices running the iOS, in particular, had significant scope to be used as assessment devices for occupational settings. Similarly, the work of Nast et al tested five apps but only one phone - the iPhone 4S - thereby essentially controlling for the phone model in their analysis of noise measurement applications[4]. Their results showed that for all apps tested, the results varied widely from that measured using a Type 1 SLM.

The current paper builds on previous work which has sought to analyse the suitability of smartphones for use as a substitute for traditional SLMs. Whereas related studies has tended to place focus on the smartphone apps themselves, this research focusses not only on testing the leading apps on two leading platforms – iOS and Android - but we also test a much wider range of smartphones than has been tested in similar studies to date.

2 METHODS

A representative sample of the most popular smartphones on the market as of March 2015 was acquired by asking students at the University of Hartford to volunteer their device for testing. In total 100 smartphones were tested; 65 were on the iOS platform while the other 35 were Android-based. For each iOS-based phone, four leading apps were tested while three apps were tested for each Android phone. This discrepancy was due to one app being taken down from the Google Play store after a small number of tests had been completed and because of this it was removed from the testing agenda. For an app to be included in the testing it had to satisfy certain criteria. These included: (1) being able to report A-weighted sound levels; (2) being able to report the sound level as a numeric value and (3) being either free or cost less than $5.00 While some apps allow for manual calibration of the in-built microphone prior to measurement, this was not completed for our experimental tests in order to simulate a typical real world situation. This conforms to the approach taken for similar testing studies[3-4]. Table 1 provides a full list of the apps tested for our study – 7 in total - for the iOS and Android phones, the developer and version. All of the apps tested met our selection criteria and all were commercial apps.

Table 1. Smartphone apps selected for testing

Application	Developer
Sound Level Analyzer Lite (iOS)_version 1.3	Toon,LLC
SPLnFFT (iOS) version 1.1	Fabien Lefebvre
Decibel Meter Pro (iOS) version 2.05	Performance Audio
UE SPL (iOS) version 2.1.1	Logitech Inc.
Sound Meter (Android) version 1.6	Smart Tools co.
Noise Meter (Android) version 2.1	JINASYS
Decibel Pro (Android) version 1.4.22	BSB Mobile Solutions Tools

For our experimental set up, we used broadband white noise in a 125 m^3 ISO 3741 compliant reverberation room[5]. This source was generated through Brüel & Kjær's Pulse Measurement System, version 18.1 and was played through a Type 4292-L OmniPower dodecahedron loudspeaker located in the centre of the room. The output voltage was adjusted in Pulse to produce a uniform sound field at 50 dB(A), 70 dB(A), and then 90 dB(A). These values were initially confirmed using both a rotating microphone boom fitted with a diffuse field microphone as well as a calibrated Brüel & Kjær Type 2250 SLM. Background noise was measured on each test day and was found to be 27 dB(A) in the reverberation room. Testing was conducted over 10 separate days. The diffuse sound field generated in the reverberation room meant that the precise location and size of the smartphone in the room did not influence the results of the study in any way. However, during measurements, phones were handheld at shoulder height by the same two individuals for the entire series of testing; all phone covers were removed prior to testing to avoid any interference with the microphone. As an experimental precaution, the room was tested immediately before and after each testing schedule to ensure that the room acoustics remained consistent across testing schedules.

For data analysis, we performed ANOVA and t-tests to assess the difference in mean values associated with each platform (iOS/Android), across apps and phone models. In addition, descriptive statistics were utilised to determine operating system, app and phone performance while standard boxplot analysis was used to assess the variability in measurement scores across apps and phone models. In order to isolate the impact of certain variables on measurement outcome, sequential regression analysis was also undertaken. Sequential regression is utilised to determine the impact of independent variables on smartphones measurement differential from reference and allows the user to enter variables or sets of variables into the regression equation after other variables have been controlled for as a separate block. This allows the researcher to determine if such variables are contributing significantly to the prediction of the measurement outcome.

3 RESULTS

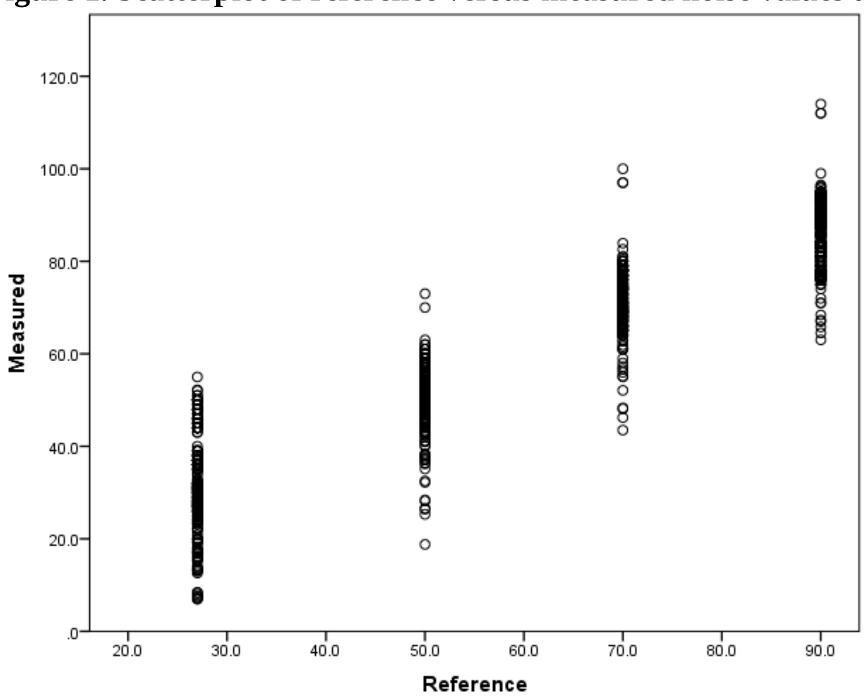
Table 2 shows descriptive statistics of the mean difference between measured values using smartphones and the pre-specified reference values. It can be seen that for all reference tests and apps (N=1472), noise measurement apps over measured the true noise level by only 1.29 dB(A). In overall terms, the data demonstrates that, on average, measurements using noise apps have a close correlation to true noise levels. The results also show that the apps are less efficient at measuring at background and high noise levels; the applications over measure the true noise level by 5.33 dB(A) at background and underestimate it by 3.57 dB(A) at 90 dB(A). However, at noise levels between background and 90 dB(A) they do an adequate job of measuring to within an acceptable degree of error which is typically +-2 dB(A). The fact that the measurement apps do a poorer job of accurately measuring at high noise levels is a concern given that environmental noise at higher levels is the key area of concern from a public health perspective.

Table 2. Descriptive statistics showing smartphones testing results by reference condition (dB(A))

Reference (dB(A)	**N**	**Mean difference from reference**	**S.D.**	**S.E.**
Background (27)	368	5.33	9.64	0.50
50	368	2.09	6.50	0.34
70	368	1.33	6.27	0.33
90	368	-3.57	6.99	0.36
Total	1472	1.29	8.12	0.21

To explore the data variability, a scatterplot comparing measured values with pre-specified reference conditions – 27 dB(A)background, 50 dB(A), 70 dB(A), 90 dB(A) – was completed and is shown in Figure 1. It demonstrates the extent of variation in measured versus reference values across the full range of measurements. The high degree of variation between measured and reference scores suggests that the reliability of smartphones for measuring environmental noise depends to a significant degree on having a relatively large number of sample data points rather than a few isolated measurements.

Figure 1. Scatterplot of reference versus measured noise values using smartphones



Turning our attention to specific phone apps, the results found that the best app was on the iOS platform (SLA Lite) with the second best app associated with the Android platform (Sound Meter). Overall, the testing regime showed that iOS apps over measured true noise levels by an average of 2.93 dB(A) (N=1052) while apps on the Android platform under measured noise levels an average of 2.79 dB(A) (N=420). While this suggests that apps on the Android platform were slightly more successful at measuring true noise levels, the high standard deviation value associated with Android apps (SD=9.58 dB(A)) highlights the greater degree of variability associated with measurement apps on that platform; in short, apps on the iOS (SD=6.81 dB(A)) were more consistent and less erratic in terms of their measurement values. Thus, while the results show that Android devices have mean values closer to true noise levels at most reference conditions, the best performing and most consistent apps in terms of measurement reliability are on the iOS platform.

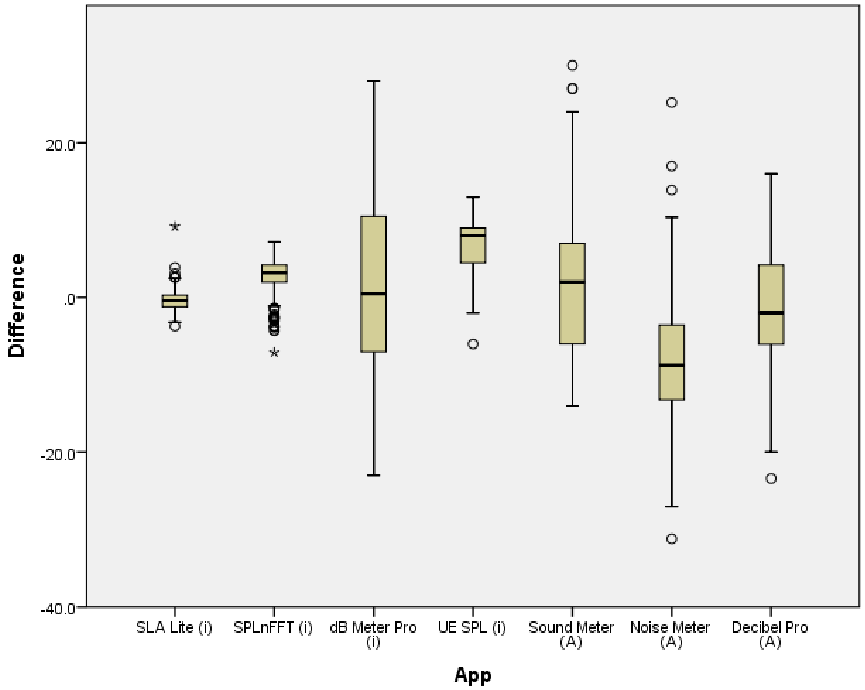
Table 3. Performance of individual apps compared to reference conditions

App	Mean	N	Std. Deviation
SLA Lite (i)	-.375	260	1.4109
SPLnFFT (i)	2.744	264	2.3617
dB Meter Pro (i)	2.458	264	11.8144
UE SPL (i)	6.822	264	3.4369
Sound Meter (A)	1.936	140	9.0492
Noise Meter (A)	-8.241	140	8.7120
Decibel Pro (A)	-2.051	140	8.1153
Total	1.295	1472	8.1180

A detailed breakdown of the differential between measurement values for individual apps and reference conditions for all tests is provided in Table 3. With regard to the performance of specific apps, the best performer in this regard was SLA Lite. Across the four reference values, the app had an average under measurement of only -0.37 dB(A) which compares favourably with SLMs. Moreover, the standard deviation associated with measurements using SLA Lite was small (1.41) highlighting the consistency of the app in terms of its measurement accuracy. Despite the ability of the app to measure accurately, one of the main drawbacks is its inability to log data over a specified time period which makes it difficult to utilise for environmental noise measurements in the field. Turning to the Android platform, the most accurate app was Sound Meter which under measured noise by 1.94 dB(A), under the typically acceptable error threshold of +-2 dB(A). It can be seen also that despite the mean values for Android apps holding up well when compared to true noise levels, the standard deviation values associated with most Android apps are typically a lot higher than those associated with iOS apps. This suggests a lack of measurement consistency for Android apps when compared to corresponding apps for the iOS.

The boxplot in Figure 2 shows a visual breakdown of the distribution of the difference between reference and measured data by noise measurement application. It can be seen that, with the exception of dB Meter Pro, the applications with the lowest degree of variability are all on the iOS platform with those on the Android platform associated with more varied data distributions. Indeed, apps such as SLA Lite and SPLnFFT, in particular, have data ranges which are considerably narrower than other apps indicating that those apps are more consistent in terms of their ability to measure environmental noise accurately. The more detailed breakdown by specific reference condition shows that the highest degree of variabilty lies at the background refence condition and also shows that Andrpid apps are associated with a higher degree of variability at all reference conditions. Moreover, at the 90 dB(A) condition there exists a signifcant number of data outliers[1] which suggests a more erratic pattern of measureement at higher noise levels when compared with the 50 and 70 dB(A) conditions.

Figure 2. Boxplot showing data distribution of difference between reference and measured values by smartphone application



In order to examine the relationship between app and measurement accuracy more concretely, a sequential regression was undertaken to examine the effect of noise measurement application on the ability of a smartphone to measure noise accurately. The results of the regression were statistically significant (p=0.00) when other factors were controlled for such as phone brand, platform and the age of the smartphone indicating a statistically significant relationship between the app being used and measurement accuracy highlighting the importance of choosing the correct app for environmental noise measurement.

4 DISCUSSION AND CONCLUSIONS

The use of smartphones for measuring environmental noise, while currently in its infancy, has significant potential in the future to act as a form of crowd sourced noise monitoring. Indeed, if smartphone-based noise measurement apps prove to be useful in the future, they could play an important role for assisting with the implementation of the EU Environmental Noise Directive[6-8].

Compared with previous studies that have tested the accuracy of smartphones for measuring noise[3-4], this study includes a much more extensive range of testing. First, it tests 100 phones of various makes and models comprising 1472 tests. Smartphones from seven manufacturers were tested comprising 18 different Android phone models and 7 different iOS models. By virtue of the testing range, smartphones across a variety of age cohorts are included in the analysis thereby reflecting to a greater extent the population of smartphones in use among the general public. Second, we tested a range of leading smartphone apps across the iOS and Android platforms. While other studies have also completed similar testing, the testing of apps

[1] Outliers are indicated by asterisks and circles.

has not been completed across such a volume and variation of phone makes and models as is included in this study.

The accuracy of noise measurement apps varied widely relative to pre-specified reference levels. Overall, there is little doubt that iOS apps performed better than Android-based apps. While some Android apps performed better than those for the iOS in terms of mean differential from reference values (e.g. Sound Meter), the high degree of measurement variability associated with such apps renders their reliability questionable. What we can say is that if a large number of sample measurements are being taken then Android apps such as Sound Meter and Decibel Pro will tend to converge on a noise measurement level that is roughly within +-2 dB(A) of the true noise levels. However, in the absence of a large number of sample measurements, iOS apps such as SLA Lite and SPLnFFT should be utilised due to their ability to measure with less variability around the mean noise level. In fact, SLA Lite was the only app accurate to within +-2 dB(A) across all of the reference conditions – background, 50, 70 and 90 dB(A) - even though other apps such as SPLnFFT (iOS) and Sound Meter (Android) performed relatively well.

Ultimately, we can conclude that noise apps are not quite ready to replace traditional SLMs but our results suggest the likelihood that as software and hardware technology improves there is ample scope for noise apps to perform an important role in crowd sourced environmental noise monitoring in the near future. The accuracy of the SLA Lite app clearly demonstrates that a combination of good hardware and software achieves noise monitoring results that are very accurate provided an adequate number of sample measurements are taken.

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