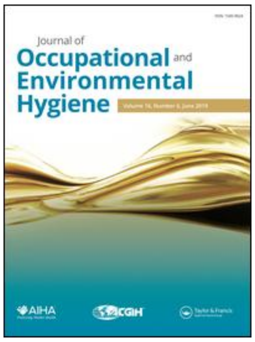

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SHORT REPORT

Evaluation of smartphone sound level meter applications as a reliable tool for noise monitoring

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ABSTRACT
Noise is a constant and ongoing health hazard across many workplaces and industries worldwide. The effective management of noise-related health effects is primarily dependent on accurate measurements of sound levels. The accuracy and feasibility of smartphone sound level meter applications (apps) for noise monitoring in occupational and environmental scenarios was tested. Ten iOS and Android smartphones were used to conduct sound level measurements with five apps for each respective platform. Five different sound signals were utilized to represent the spectra present in an occupational environment, at four different reference sound levels (60, 70, 80, and 90 dBA) for a total of 1,000 tests. A calibrated Larson Davis LxT sound level meter was used as a reference. Results suggest that across all four measured sound levels the difference in smartphone app performance on the two platform is fairly nuanced. However, at the 90dBA sound level Android apps consistently underreport sound levels. This study concludes that some apps have the possibility to be appropriate for use only as screening tools and cannot be used for accurate determination of sound levels.

KEYWORDS
Occupational noise; noise exposure; noise measurement; smartphones; sound level meter apps

Introduction

Modern smartphones have become a necessary piece of technology among adults and teenagers in the developed world as evidenced by a U.S. smartphone penetration rate of 82%.[1] Of the 344 million smartphones sold in the second quarter of 2016, 86% utilized the Android operating system and 13% utilized the iOS operating system. These two operating systems account for 99% of worldwide smartphone shipments.[2]

The evolution of smartphones has occurred alongside the evolution of smartphone applications or "apps." These apps are designed to operate on the smartphone touch interface in a user-friendly manner.[3] Combined with the prevalence of smartphones, sound level meter apps present the distinct possibility for use as a portable sound level meter (SLM) in nearly everyone's pocket.

Disabling hearing loss currently affects over 466 million people worldwide; with nearly half of these cases avoidable through means of primary prevention.[4] It has been estimated that somewhere between 16–24% of disabling hearing loss cases are occupationally related,[5] illustrating the importance of assessing smartphone SLM app accuracy to help prevent this global occupational hazard.

In 2016, noise induced hearing loss (NIHL) claims exceeded \$50 million[6] in Ontario, Canada alone. Prolonged exposure to noise can cause physical and psychological stress, cardiovascular disease, reduced productivity, and contribute to workplace accidents and injuries.[7–10]

The two main types of SLMs are Class 1 and Class 2. Class 2 SLMs are generally used for field measurements[11] and are most applicable to this study. According to the American National Standards Institute (ANSI) S1.4-2014/Part 1/IEC 61672-1:2013, the total allowable error for an SLM measuring noise at frequencies between 20 Hz and 20 KHz is +3 dB up to +5, $-\infty$ dB for a Class 2 instrument.[11]

Current devices for occupational noise testing such as dosimeters and SLMs are highly accurate but relatively expensive and require some training to use. Whereas an SLM app can be inexpensive and simple to use, presenting a possible gap that SLM apps may fill. Additional SLM app advantages include portability and ease of access. The potential to have existing smartphones operating as Class 2 SLMs in occupational environments could play a critical role in reducing risks associated with prolonged worker exposure to high sound levels.

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uoeh.

Several studies have explored the accuracy of smartphone sound level measuring apps to assess occupational noise exposures. Kardous and Shaw[12] concluded that certain apps on iOS devices could be considered accurate and reliable but, Android apps on a whole could not be considered reliable for the same use.

Murphy and King[13] similarly concluded that iOS apps performed better than Android apps, also noting that increased variability between measurements on Android vs iOS platforms.

Robert et al.[14] also conducted a study to assess the accuracy of iOS smart devices in measuring noise exposure. They used different types of microphones and iOS devices to measure pink noise ranging from 60–100 dBA. Their results showed that it may be possible to use iOS smart devices with specific combinations of apps and calibrated microphones to collect reliable occupational noise exposure data.

Lastly, Nast et al.[15] conducted a similar study where they concluded that of the apps tested, no app was accurate enough for use without calibration due to the nonlinearity of errors across different apps and different sound levels

The present study aims to analyze the accuracy of sound level measurements obtained using various smartphone applications on the iOS and Android platform to help determine their applicability in occupational and environmental settings. While past studies have measured sound levels in the presence of just white or pink noise, the present study conducts sound levels measurements with five sound signals including steel making, conveyor belt noise, speech signal, white noise, and pink noise.

Methods

Materials

Ten different smartphones were collected from students on the Ryerson University (Toronto, Ontario) campus. These were considered a representative sample of the most popular smartphones at the time of testing. Five devices were iOS and five were Android. Table 1 lists the model/manufacturer, software version, condition, and microphone location of each device. Phones were randomly selected depending on availability and ranged in age and condition. The condition of the phone was determined based on the age: “Good” $= \leq 1$ year; “Average” $= > 1$ year but < 2 years; “Not Good” ≥ 2 years.

Five iOS and five Android apps were downloaded and installed on devices for testing. “Noise Exposure” and “Decibel 10th” were used on both platforms. A complete list of all apps used in the study can be found in Table 2. Apps selection was based on their ability to meet the following criteria: (1) free to download; (2) high user ratings and/or positive reviews at the time of assessment; and (3) ability to report measurements instantaneously and as a numerical value. In-app calibration was offered by some apps but was not used and app setting were used as default (i.e., slow response) in this study in order to best simulate an average user’s real-world experience as was performed in similar studies.[12–14]

Table 1. Smartphones tested and their software, microphone type, and subjective condition.

Phone	Software Version	Microphone Location	Condition
iPhone 6	iOS 9.3.3	Bottom of phone	Good
iPhone 6 Plus	iOS 9.3.3	Bottom of phone	Good
iPhone 5s	iOS 9.33	Bottom of phone	Not Good
iPhone SE	iOS 9.3.3	Bottom of phone	Good
iPhone 4s	iOS 7.1.2	Bottom of phone	Not Good
Samsung Galaxy S4	Android 5.0.1	Bottom of phone	Not Good
LG Nexus 5x	Android 6.0.1	Bottom of phone	Good
Huawei Nexus 6p	Android 6.0.1	Back of phone	Good
Motorola G 2nd Gen	Android 6.0	Top of phone	Average
Samsung Galaxy S7	Android 6.0.1	Bottom of phone	Good

Set up

Five different sound signals (white noise, pink noise, speech, occupational steelmaking, and conveyor belt) were used in the experimental setup. These mp3 sound signals were obtained from a sound library and had two audio channels with a sampling rate of 44.1 KHz. It is important to note that noise signals were cut and looped to provide a consistent sound signal for all measurements. An Apple MacBook Pro (containing all sound files) was connected to a Pioneer AV receiver (Model VSX-524-K) and five Polkaudio loudspeakers (four of which were of model RM6751 and the other model RM6752), with the local (two-channel) sound card on the laptop computer being used for digital to analog conversion of the signals.

The reference SLM and two smartphones were positioned in front of the speaker system setup. Sound level was manually controlled using the volume knob of the receiver. Signals were generated at 60, 70, 80, and 90 dBA, confirmed using a Larson Davis SoundTrack LxT (factory calibrated 2 weeks prior to testing).

Prior to each testing session the SLM was calibrated using a Larson Davis CAL200 calibrator. Background sound level measurements never exceeded 40 dBA. Smartphones and the reference SLM were mounted on tripods at a height of 91 cm and 99 cm

Table 2. Applications tested on each of the smartphones along with their manufacturer and version numbers.

App	Developer	Logging Ability	Web Link
Noise Exposure (iOS) version 2.0.1	Arbetsmiljoverket	Yes	https://itunes.apple.com/ca/app/noise-exposure/id418022274?mt=8
*Decibel 10th (iOS) version 4.3.5	SkyPaw Co Ltd	Yes	https://itunes.apple.com/ca/app/decibel-10th-professional/id448155923?mt=8
Sound Meter- Noise Power Level and Decibel Meter (iOS) version 1.0.0	LQH Apps	No	https://itunes.apple.com/ca/app/sound-meter-noise-power-level/id1088469601?mt=8
Sound Level Analyzer (SLA) Lite- Simple dB Meter (iOS) version 2.2	TOON,LLC	No	https://itunes.apple.com/ca/app/sound-level-analyzer-lite/id886090835?mt=8
**Sound Level Meter (Voice Meter) (iOS) version 1.8	Seong Eon Kim	No	https://itunes.apple.com/ca/app/sound-level-meter-voice-meter/id912170360?mt=8
Noise Exposure (Android) version 2.0.1	Arbetsmiljöverket	Yes	https://play.google.com/store/apps/details?id=se.av.buller&hl=en
*Decibel 10th (Android) version 1.4.1	SkyPaw Co Ltd.	Yes	https://play.google.com/store/apps/details?id=com.skypaw.decibel
Sound Meter- Decibel (Android) version 1.1.1	Melon Soft	Yes	https://play.google.com/store/apps/details?id=app.melon.sound_meter
Sound Meter (Android) version 3.1.6	Abc Apps	Yes	https://play.google.com/store/apps/details?id=com.gamebasic.decibel
Sound Meter & Noise Detector (Android) version 1.2	Tools Dev	Yes	https://play.google.com/s.***

*App is now called Decibel X: dB, dBA Noise Detector but this study utilized an earlier version of the app
**App is now called iSound Level Meter (Voice Meter) but this study utilized an earlier version of the app
***Sound meter and noise detector:
https://play.google.com/store/apps/details?id=coocent.app.tools.soundmeter.noisedetector

Figure 1. The setup used during this experiment.

from the speaker. Measured distance between the mounted SLM and smartphones was approximately 15 cm (Figure 1). All smartphone cases and covers were removed prior to testing to prevent any possible interference with microphones and any discrepancies in results that may occur due to not all collected phones having a case/cover. Smartphone microphones were oriented toward the speakers. The sound source was turned on, while the SLM was given time to equilibrate and then a near-instantaneous reading was recorded from the smartphone. Max and peak values were not recorded.

Single measurements were recorded for each app, on each smartphone model, at each sound level for all five sound signals totaling one hundred measurements per app and one thousand measurements in total (Table 3). Spectral analysis for all sound signals is displayed in Figure 2.

The sound range of 60–90 dBA was used to represent the most likely occupational noise exposure levels present in real life scenarios.[3] Directionality was not taken into consideration in this study as pilot study testing showed no significant difference in the results (<2.0 dB). Furthermore, during the pilot study

Table 3. Tested variables in the study.

Variable	Specifics
Smartphones	Five iOS and five Android devices
Sound Signals	White noise, Pink noise, Speech file, Steelmaking, and Conveyor Belt
Sound Levels (dBA)	60, 70, 80, and 90
Apps	Five iOS and five Android applications

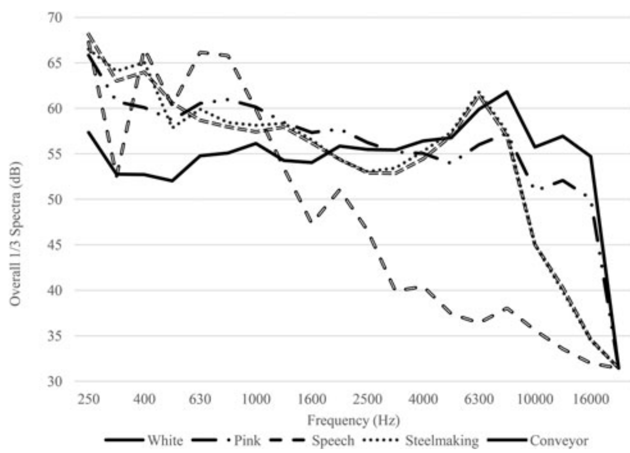

Figure 2. Spectral analysis of all five sound sources in the study.

repeated measurements were taken on two randomly chosen smartphones (one from each platform) using all five apps at all four sound levels and for all five sound signals. Results showed no significant difference (<2.0 dB) between repeated measurements, therefore conducting repeated measurements on each device was considered not necessary.

Results

To facilitate the comparison between sound levels, all measurements were converted to an error reading (i.e., difference from the reference sound level). Results were tested for normal distribution using the Kolmogorov–Smirnov statistic. To determine if the noise source influenced the error readings, a repeated measures (RM) analysis of variance (ANOVA) was completed, testing for a significant difference between noise signal sources for each phone and sound level. Mauchly's test was used to test for sphericity, to ensure that the variance of differences between all conditions was equal (an important assumption within a RM-ANOVA). When the results were found to be significant, the Greenhouse-Geisser statistic was used to correct for the degree of violation of sphericity that occurred in our dataset. A RM ANOVA was also completed for the two phone applications that were identical across the two platforms: Noise Exposure and Decibel 10th. All statistical tests were completed

Table 4. Measurements results at reference sound levels by platform. Values in brackets represent the minimum and maximum values measured at each sound level.

Sound Level	Platform	N	Mean	S.D.
60	iPhone	125	65.4 (40.6–79.8)	10.0
	Android	125	57.2 (36.3–72.6)	7.6
70	iPhone	125	74.8 (49.9–86.4)	9.5
	Android	125	66.7 (45.0–82.5)	7.9
80	iPhone	125	82.9 (60.3–92.5)	8.1
	Android	125	75.8 (55.0-88.1)	7.1
90	iPhone	125	89.5 (68.6–95.4)	6.2
	Android	125	80.5 (63.0–95.0)	6.5

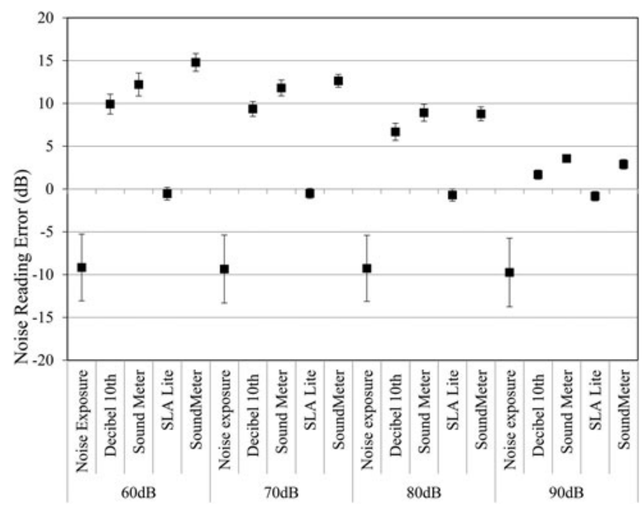

Figure 3. Average error in the noise readings (app reading – reference reading) and standard deviations across five different iPhone models. *3rd app: Sound Meter – Noise Power Level Sound Level Meter (Voice Meter) 5th app: SoundMeter by Faber Acoustical

using SPSS (version 22.0 IBM Corp., Armonk, NY) and an alpha level of .05 was used as the minimum level of significance.

To examine the statistical relationship between tested variables (sound levels determined by the app) and reference measurements (sound level determined by the SLM), Levene's Test of Equality of Error Variances was conducted. It showed a significant difference ($p < 0.05$) between the app used and obtained results. The statistical test also showed a significant relationship ($p < 0.05$) between which platform measurements were taken on, and the results produced. Since statistical testing showed a significant between-phone effect in the RM-ANOVA completed for each phone type: $F(1,4)_{(iOS)} = 10.4$, $p = .03$, $F(1,4)_{(Android)} = 8.4$, $p = .04$, no further statistical testing was completed.

Descriptive data displayed in Table 4 shows a breakdown of the data by phone platform, showing measurements obtained on the iOS platform are usually higher than reference sound levels; the opposite was true for the Android platform.

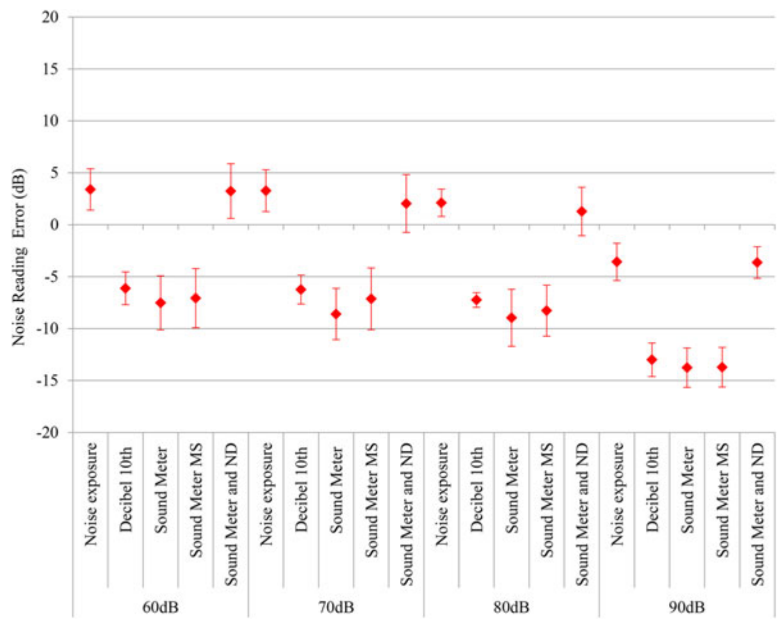

Figure 4. Average error in the noise readings (app reading – reference reading) and standard deviations across five different Android models. *2nd app: Sound Meter by ABC 3rd app: Sound Meter by Melon Soft and 5th app: Sound Meter and Noise Detector. Titles were shortened for clarity.

Table 5. Effect of sound level category and application for iOS and Android devices.

			Sound level		Application		Interaction	
	Mean	SE	F(3,12)	p	F(4,16)	p	F(12,48)	p
iOS	3.2	1.0	45.3	0.001	21.3	.009	35.1	0.001
Android	−5.0	1.7	10.5	0.03	26.7	.004	0.5	0.1

A comparison between phone models on the same platform for the apps Noise Exposure and Decibel 10th illustrated a statistically significant effect only for sound level $F(1,4) = 16$, $p < .001$, but no effect for phone type.

Figures 3 and 4 display deviation from reference condition for each app, at each sound level for both iOS and Android devices, respectively. Average values are displayed alongside their standard deviation. The data reveal that for iOS devices, four apps had low standard deviations with one app having a fairly large standard deviation (Figure 3). On the other hand, Android apps displayed larger standard deviations on average (Figure 4). Thus, overall, the majority of iOS apps had smaller error ranges than their Android counterparts, outside of the performance of the Noise Exposure iOS app. Statistical analysis showed a significant effect for sound level category and application for both types of phone with an interaction effect (Table 5). As sound level increased, the error magnitude decreased for iOS devices except for readings using the Noise Exposure application. A similar trend was not apparent with the Android phones. A significant between-phone effect occurred for both platforms, indicating that platform influences results. Since the type of sound signal did not have a significant effect on the accuracy of apps, the results were displayed as average values.

Figure 5 displays a series of boxplots exhibiting the variation of results by app at all four reference sound levels. The errors for individual sound level readings nested within the noise source ranged from -18.8 dB, to +18.6 dB when using iOS devices, and from -20.6 dB, to 10.5 dB when using Android devices. When considering the variation of measured values on all iOS devices, it was observed that three out of five apps overestimated the noise values and two underestimated them. This pattern was observed across all four sound levels tested. Apps were arranged on the boxplots from least to most accurate, indicating that "SLA Lite" was the most accurate app with the least variation in its results. All five Android apps across all four sound levels produced a large range of values (Figure 5). Although Android SLM apps lacked precision, "Sound Meter and Noise Detector" was determined to be the most accurate app on the platform (at three out of four sound levels). All Android apps either had a high degree of variability in their measured results or were not accurate when compared to reference values. These results were exacerbated at the 90-dB sound level.

Discussion

The present study tested the accuracy of 10 different SLM apps on 10 different smartphones at varying

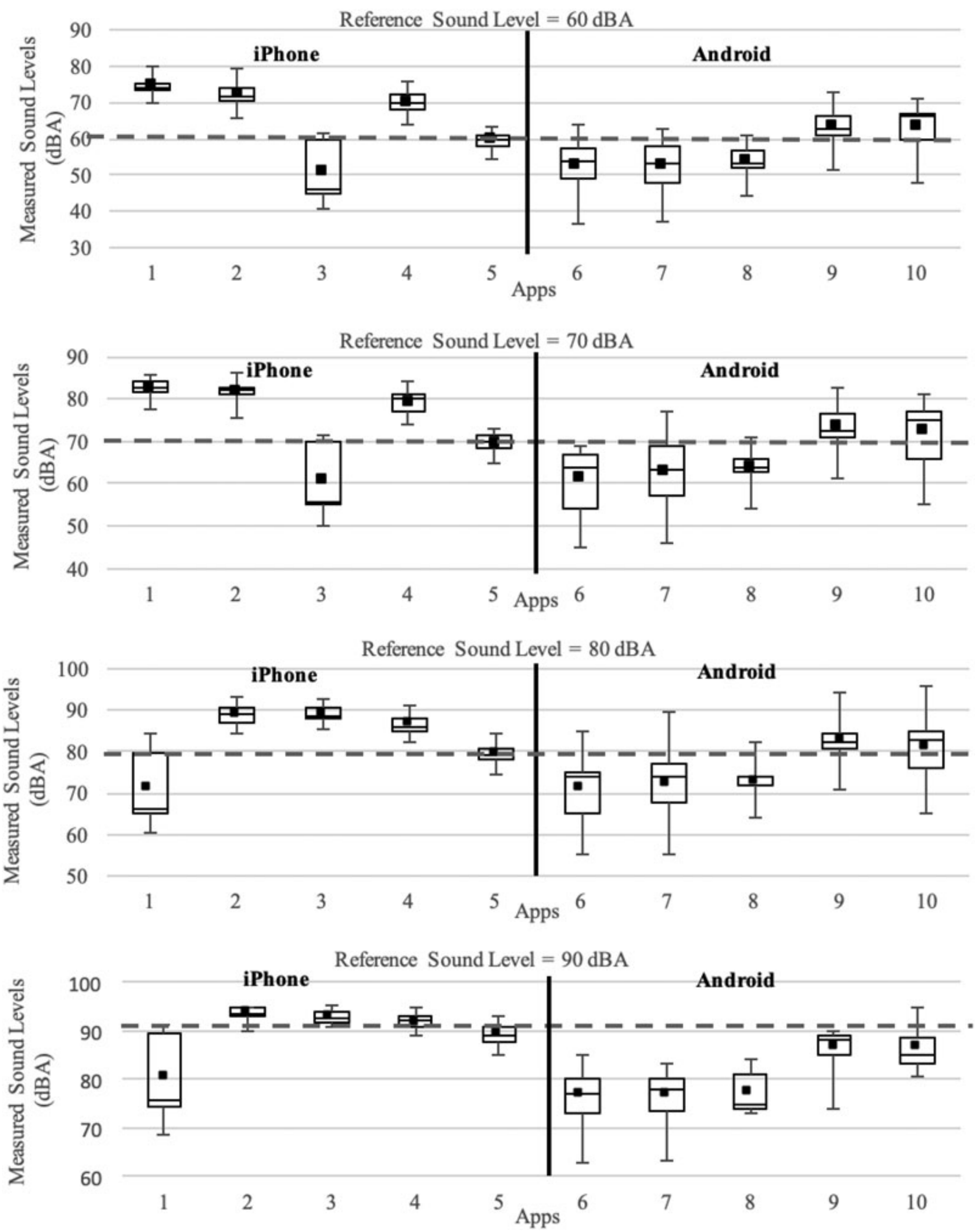

Figure 5. Boxplots showing the variation of data of measurement results for all tested smartphone apps compared to reference conditions of 60, 70, 80 and 90 dBA as shown by the dotted line. Number on x-axis represent various apps tested as follows: 1 = Noise Exposure, 2 = Sound Meter, 3 = SoundMeter, 4 = Decibel 10th, 5 = SLA Lite, 6 = Sound Meter by Abc, 7 = Sound Meter by Melon Soft, 8 = Decibel 10th, 9 = Noise Exposure and 10 = Sound Meter and Noise Detector

sound levels using five different sound signals. It differed from previous studies by testing a wider range of sound signals. The goal was to determine if a relationship exists between the type of sound signal used and accuracy of measurement results. This allowed for a more accurate representation of the various ranges of sound expected to be present in an occupational or environmental scenario.

Results showed varying degrees of performance for SLM apps. Overall, apps on the iOS platform generally overestimated sound levels and exhibited a larger range of variability in measurements. This larger degree of variability was primarily driven by the Noise Exposure app, which had a high range of error across all sound levels. These findings were also true with regards to performance of phone models and sound signals on both platforms (Figure 5). On the other hand, three out of five apps on the Android platform underestimated sound levels, while the remaining two overestimated them. The range of average errors on the Android platform was lower than those seen on the iOS platform, while exhibiting a large degree of variability between measurements at all sound levels. This is concerning because of the correlation between higher sound levels and damaging health effects occurring. Although Android apps had averages closer to reference conditions across all sound levels, it was only because of an approximately equal distribution of measurements above and below the reference values.

The top performing app on the iOS platform (and overall) was SLA Lite, with a mean difference from reference of -0.7 ± 2.1 dB across all sound levels (Figure 3). Additionally, SLA Lite was the only app that was accurate (within ± 1.0 dB) across all individual reference levels (60, 70, 80, and 90 dB) tested. The results for SLA Lite are well within agreement of the total allowable error range found in ANSI S1.4-2014 and indicate that SLA Lite holds the best potential of the tested apps for use by the average person for determining occupational/environmental sound levels for screening purposes.

The top performing app on the Android platform was Sound Meter and Noise Detector which had a mean difference of 0.7 ± 6.4 dB (Figure 4). However, due to its large standard deviation and inconsistency in measurement results at individual sound levels, it was deemed to be inaccurate.

It was found that on iOS devices, three of five apps overestimated sound levels at three of four sound levels measured whereas two Android apps overestimated sounds levels between 60 and 80 dB while three apps underestimated sound levels. Furthermore, it was observed that all Android apps underestimated sound levels at 90 dB (Figure 4). Android smartphones underestimated values by approximately 13 dB for three of the five apps that were evaluated. Additionally, individual differences from the reference value were much greater (Figure 5). A possible explanation as to why Android devices are found to significantly under perform at 90 dB may be due to a variation in their filters or its limiting circuits.

A possible explanation for the discrepancy observed between Android and iOS results is various hardware manufacturers of Android devices compared against the single manufacturer of iOS devices. Different smartphone manufacturers are highly likely to use different hardware parts such as the microelectromechanical systems (MEMS) microphone and other audio components that have varying levels of quality. Since iPhones have a single hardware supplier and various manufacturers, they are more likely to use the same iteration of MEMS microphones and audio components across their various smartphone models, resulting in less variability. This difference in the quality of audio components has been speculated to be responsible for subpar results in Android performance found in previous studies.[12] Another explanation for the source of discrepancy is that Android software for the smartphones themselves and the apps are not as frequently updated as their iPhone counterparts, which can ultimately affect the measurement results obtained on the platform.

While it is believed that these apps and phones are representative of those which are commonly used in the general population, there are some limitations in our study. To begin with, this study was not comprehensive as the number of apps and smartphones tested were limited to the 10 devices and apps used. Furthermore, this study was conducted using only free apps which were selected from the App or Play store. The variation in reliable free apps that met testing conditions set forth was limited and hence limited apps tested. While some apps offered the ability to calibrate and adjust frequency weightings, the settings were kept at default to mimic usage by the average person. This study also only took into consideration the accuracy of built-in microphones. The results may differ if smartphones equipped with external microphones were also tested. Lastly, while most of the phones were relatively new, their age and condition was not taken into consideration in this study.

Conclusion

It was generally found that across all four measured sound levels the difference in smartphone platform performance was not clear cut. However, at the 90 dBA sound level Android apps consistently underreported sound levels. This is concerning due to the detrimental health effects that can occur at these sound levels or higher.

From the results obtained in this study, it can be concluded that most of the apps studied are not ready to be used for compliance purposes. However, an app such as SLA Lite has the potential to be used as a screening tool in occupational scenarios due to its consistency across all sound levels and low error. Overall accuracy of these apps is generally inconsistent regardless of phone platform, phone model, sound level, and sound type therefore a general correction factor cannot be applied.

It is important to note that the apps were evaluated as installed without calibration. This is a reasonable choice because it is reflective of how most of the apps would be used. However, apps which can be calibrated or corrected do have the ability to further increase their accuracy. The results from this study have reinforced findings from previous studies.

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