NIOSH Sound Level Meter Application (app) for iOS devices

Hearing Loss Prevention Team

Engineering and Physical Hazards Branch

Division of Applied Research and Technology

NIOSH Sound Level Meter

Developed in collaboration by EA LAB, Inc. under MOU agreement between NIOSH and EA LAB

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Why did NIOSH develop this app?

NIOSH estimates that 22 million workers are exposed to hazardous noise levels every year. In addition to damaging workers' quality of life, occupational hearing loss carries a high economic price to society. The NIOSH hearing loss team evaluated 192 sound measurement applications (apps) for the iOS and Android platforms to examine their suitability and accuracy in relation to professional sound measurement instruments. Of the 192 apps, 10 iOS apps met our selection criteria for functionality, features, and calibration capability, and only 4 apps met our accuracy criteria of (± 2 dB(A) mean difference from the reference type 1 sound level meter). The results were published in the Journal of Acoustical Society of America (JASA): Evaluation of smartphone sound measurement applications, Kardous and Shaw 2014. A followup study on the use of smartphone with external microphones was published in JASA in 2016 (Evaluation of smartphone sound measurement applications (apps) using external microphones—A follow-up study, Kardous and Shaw 2016), the study revealed that apps used with external calibrated microphones show close agreement with Type 1 sound level meter (accuracy within ± 1 dB(A) of reference type 1 sound level meter.

The studies also revealed that most commercially available sound measurement apps lacked the accuracy and functionality necessary to conduct occupational and general-purpose noise measurements. As a result, NIOSH hearing loss researchers collaborated with one of the 4 app developers to develop a free sound measurement app that can be distributed to the occupational safety and health community as well as the general public. NIOSH signed an MOU agreement with EA LAB in February 2015 to develop the NIOSH Sound Level Meter app. The app was subjected to the same testing requirements that were established in the Kardous and Shaw studies.

The ubiquity of smartphones and the sophistication of current sound measurement applications present a great opportunity to revolutionize current data collection and surveillance practices for noise. Through the use of crowdsourcing techniques, workers around the world may be able to collect and share workplace (or task-based) noise exposure data using their smartphones. Scientists and occupational safety and health professionals can rely on such shared data to build job exposure databases and promote better hearing health and prevention efforts. In addition, the ability to acquire and display real-time noise exposure data raises workers' awareness about their work (and off-work) environment and allows them to make informed decisions about hazards to their hearing. A NIOSH-developed and branded occupational sound measurement smartphone app will help advance the NIOSH mission by translating knowledge of occupational sound measurement into a practical and informational product that will be available to more than 1.3 billion active iOS devices worldwide.

Figure 1. The main screen of the NIOSH SLM app (shown with an external microphone on iPhone 8)

Does this app comply with ANSI or IEC sound level meter or noise dosimeter standards?

Professional sound level meters (SLMs) must comply with national and international standards such as the American National Standards Institute (ANSI) S1.4-2014), Specifications for Sound Level Meters and International Electrotechnical Commission (IEC) 61672, Sound Level Meters: Specifications (ANSI adopted the IEC standard in 2014). ANSI/IEC standards specify acoustical, electrical, and environmental tests with indicated tolerance limits and measurement uncertainties that are specified in decibels over a wide frequency range (typically from 10 Hz – 20 kHz). Such tests must account for level linearity, directionality, time and frequency-weighting responses, tone bursts, radio frequency interference, and atmospheric and environmental conditions. The standards also specify that these tests shall be made on the complete instrument, including the microphone and pre-amplifier.

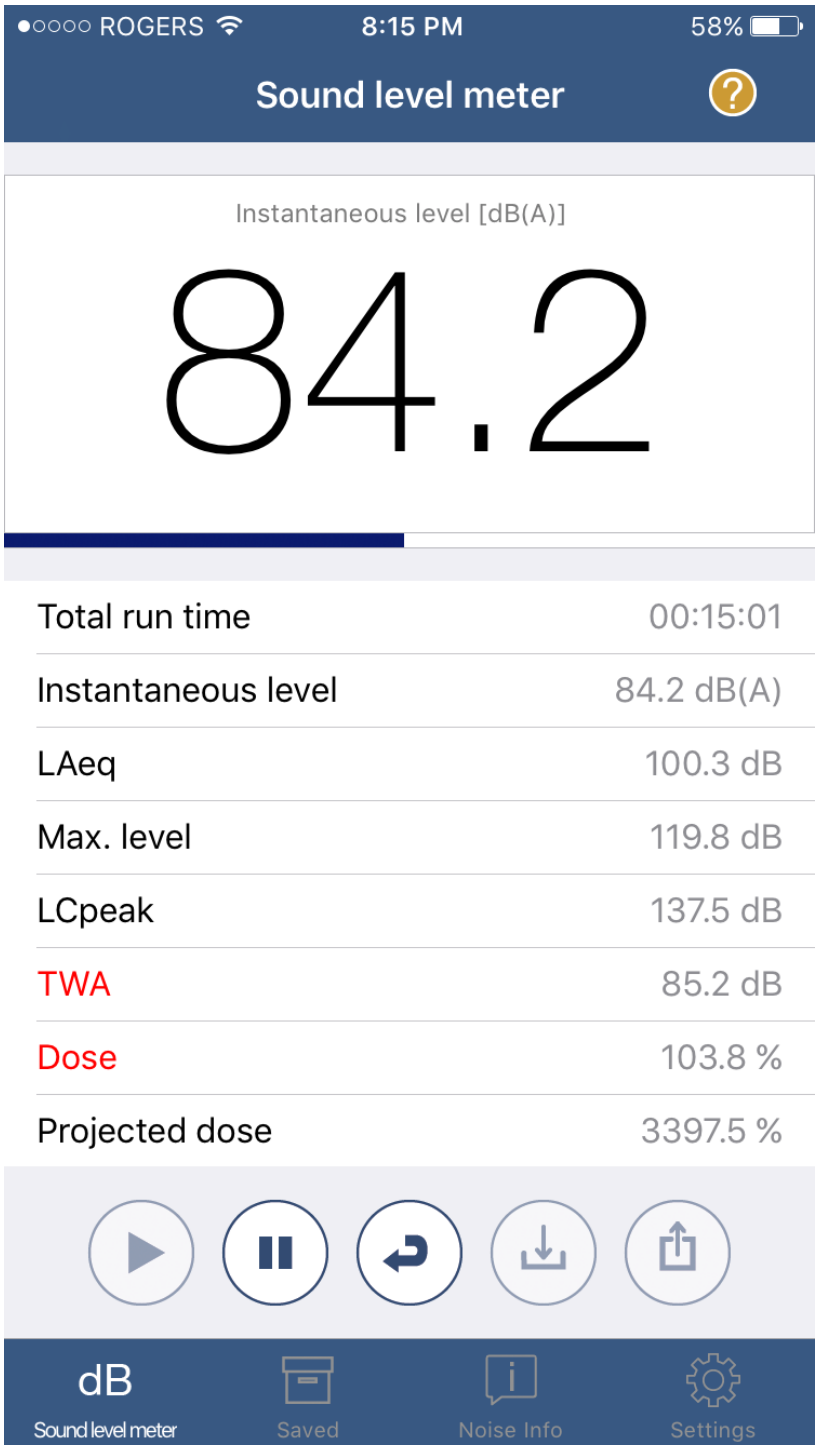
In 2018, EA LAB and NIOSH researchers evaluated the app's performance as part of a system (iPhone + external microphone) for compliance with type 2 requirements of IEC 61672/ANSI S1.4 standard: Sound Level Meters – Part 3: Periodic Tests. The results were published in the Applied Acoustics Journal [Celestina et al. 2018].

Celestina, M., Hrovat, J., & Kardous, C. A. (2018). Smartphone-based sound level measurement apps: Evaluation of compliance with international sound level meter standards. Applied Acoustics, 139, 119-128. https://doi.org/10.1016/j.apacoust.2018.04.011

NIOSH and EA LAB continue to work towards achieving compliance with Part 1 and 2 or IEC 61672, but as of today, this is the only app that has shown any compliance with sound level meters standards. This app is meant to serve as a practical tool to raise awareness about noise levels in the workplace. Increased awareness could lead workers and managers to request full professional noise surveys and implement engineering controls or hearing conservation programs to reduce the risk of noise-induced hearing loss.

Main Screen (Sound Level Meter)

Once the user launches the app, they will be presented with a main screen (dB icon highlighted on the bottom left corner). The top half of the screen shows a readout of the sound level using the built-in microphone (or external microphone if used) and reports the instantaneous sound level in A, C, or Z-weighted decibels. The weighting is user-selectable and can be accessed in the Settings screen.



What are the main features of the NIOSH SLM app?

The NIOSH Sound Level Meter app has many important features: it provides a readout of the sound level using the built-in microphone (or with an external microphone) and reports the instantaneous sound level in A, C, or Z-weighted decibels. The weighting is user-selectable and can be accessed in the "Settings" screen. The app also reports the main metrics that are important for proper occupational noise measurements: run time (total time), A-weighted equivalent sound level (LAeq), maximum level measured during the current run time, C-weighted peak sound pressure level (LCpeak), time-weighted average (TWA), and dose. The app also contains basic information about noise and hearing loss prevention. In addition, the app allows the user to save and share measurement data using the smartphone other communication and media features. If location services are enabled, the app can use the GPS feature to provide an exact geospatial location of the location of the noise measurement.

- **Total run time**: Total run time for the current measurement
- **Instantaneous level**: Default sound pressure level in A, C, or Z-weighted decibels [dB(A), dB(C), dB(Z)].
- **LAeq**: Equivalent (averaged every second) continuous sound level in A-weighted decibels [dB(A)].
- **Max level**: Highest sound pressure level during a measurement period.
- **LCpeak**: Peak sound pressure level in C-weighted decibels [dB(C)].
- **TWA**: Time-weighted average is the sound level accumulated over any time period, but with its average computed over an 8-hour time period.
- **Dose**: A percentage of the maximum allowable daily noise dose. Exposures at 100% or above are considered hazardous.
- **Projected Dose**: The current noise dose, over the current measurement duration, projected forward over 8 hours (assuming the sound level remains constant over that same 8-hour period)

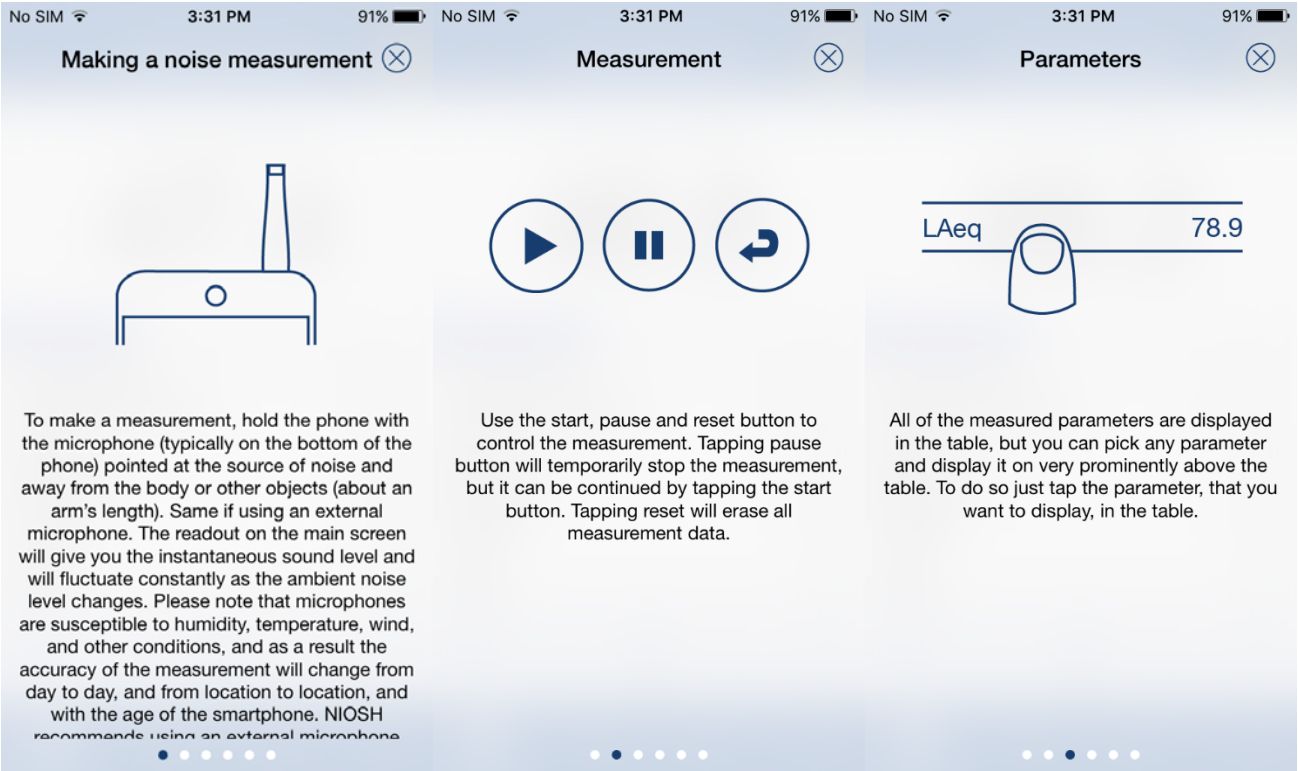
On the bottom of the screen, there are five major buttons: Start, Pause, and Reset:

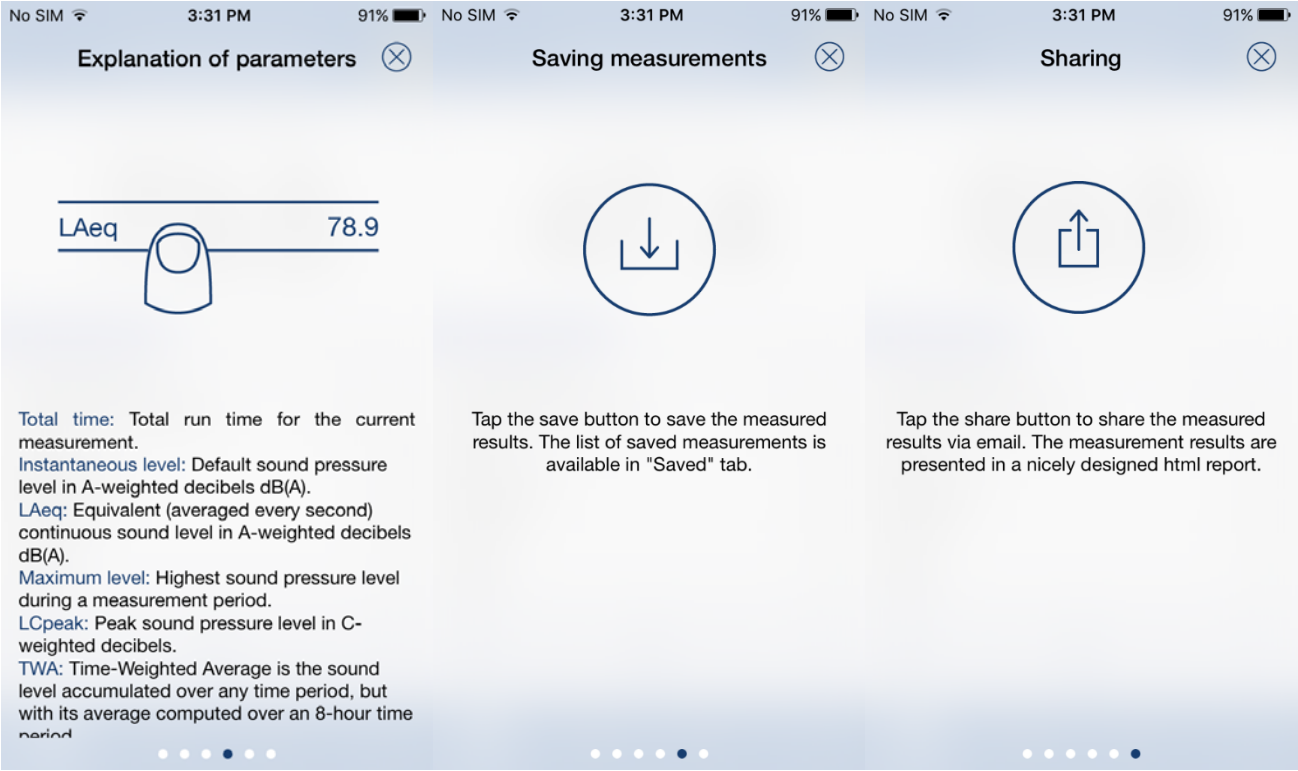
The app will give the user a warning before reset, Save, and Upload (through email)).

A permanent bar at the bottom of the screen allows the user to switch between the main 4 screens of the app – Soundlevelmeter (dB), Saved, Noise info, and Settings.

The user can toggle back and forth between these screens and can also use the ← button at the top left of the screen to go back to the previous screen.

There is a help  button that the user can select to get more information about the specific screen:





How to interpret the results or readouts of the app

NIOSH establishes recommended exposure limits (REL) for various hazards on the basis of the best available science and practice. The REL for noise is 85 decibels, using the A-weighting frequency response an 8-hour average, usually referred to as time-weighted average (TWA). Exposures at or above this level are considered hazardous. OSHA sets legally enforceable permissible exposure limits (PEL) that require employers to take actions to reduce worker exposures. The OSHA PEL for noise is 90 dB(A) as an 8-hr TWA based on a 5-dB exchange rate.

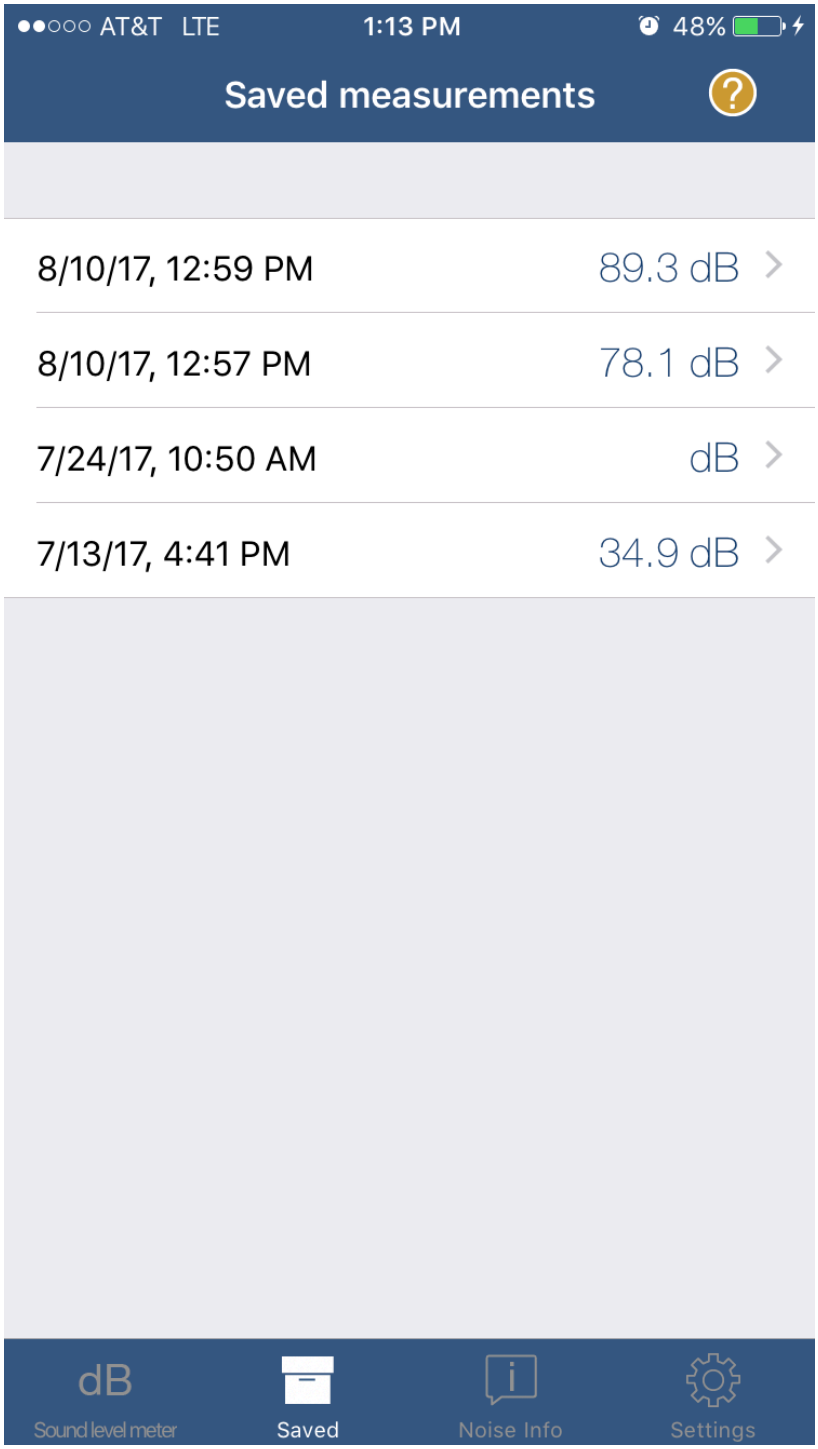
Occupational standards specify a maximum allowable daily noise dose, expressed in percentages. For example, a person continuously exposed to 85 dB(A) per NIOSH or 90 dB(A) per OSHA over an 8-hour work shift, will reach 100% of their daily noise dose. The noise dose is based on both the sound exposure level and how long it lasts (duration). This dose limit uses a 3-dB time-intensity tradeoff commonly referred to as the exchange rate or equal-energy rule: for every 3-dB increase in averaged noise exposure, the allowable exposure time is reduced by half. For example, if the exposure increases to 88 dB(A), workers should be exposed for only 4 hours. Alternatively, for every 3-dB decrease in averaged noise exposure, the allowable exposure time is doubled, as shown in the table below.

Time-Weighted Average (TWA)	Time to reach 100% daily noise dose
85 dB(A)	8 hours
88 dB(A)	4 hours
91 dB(A)	2 hours
94 dB(A)	60 minutes
97 dB(A)	30 minutes
100 dB(A)	15 minutes

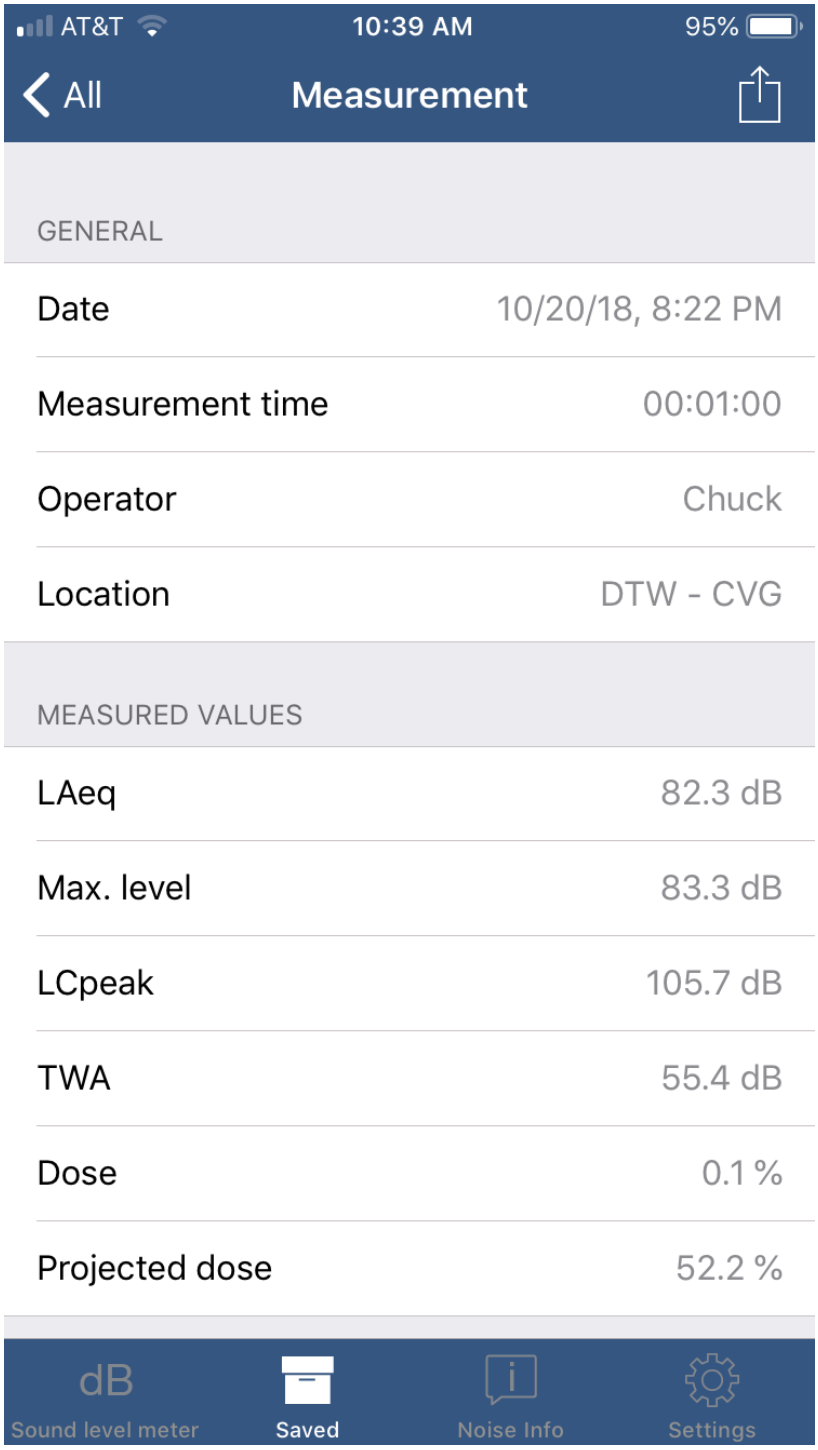
It is important to differentiate between noise level and time-weighted average noise exposure. While noise levels describe the intensity of sounds at a given point in time, the NIOSH exposure limits are set as time-weighted average exposures over periods of time. If sound level measurements consistently exceed 85 dB(A), we recommend that you follow up with a professional such as an industrial hygienist or occupational safety and health specialist to conduct a professional noise survey at your workplace. Remember, protecting your hearing is a good health practice no matter where your ears are!

Saved measurements screen

The second screen gives the user a list of “Saved measurements” with date and time stamp and the TWA for that specific measurement. Each saved measurement is stored separately.

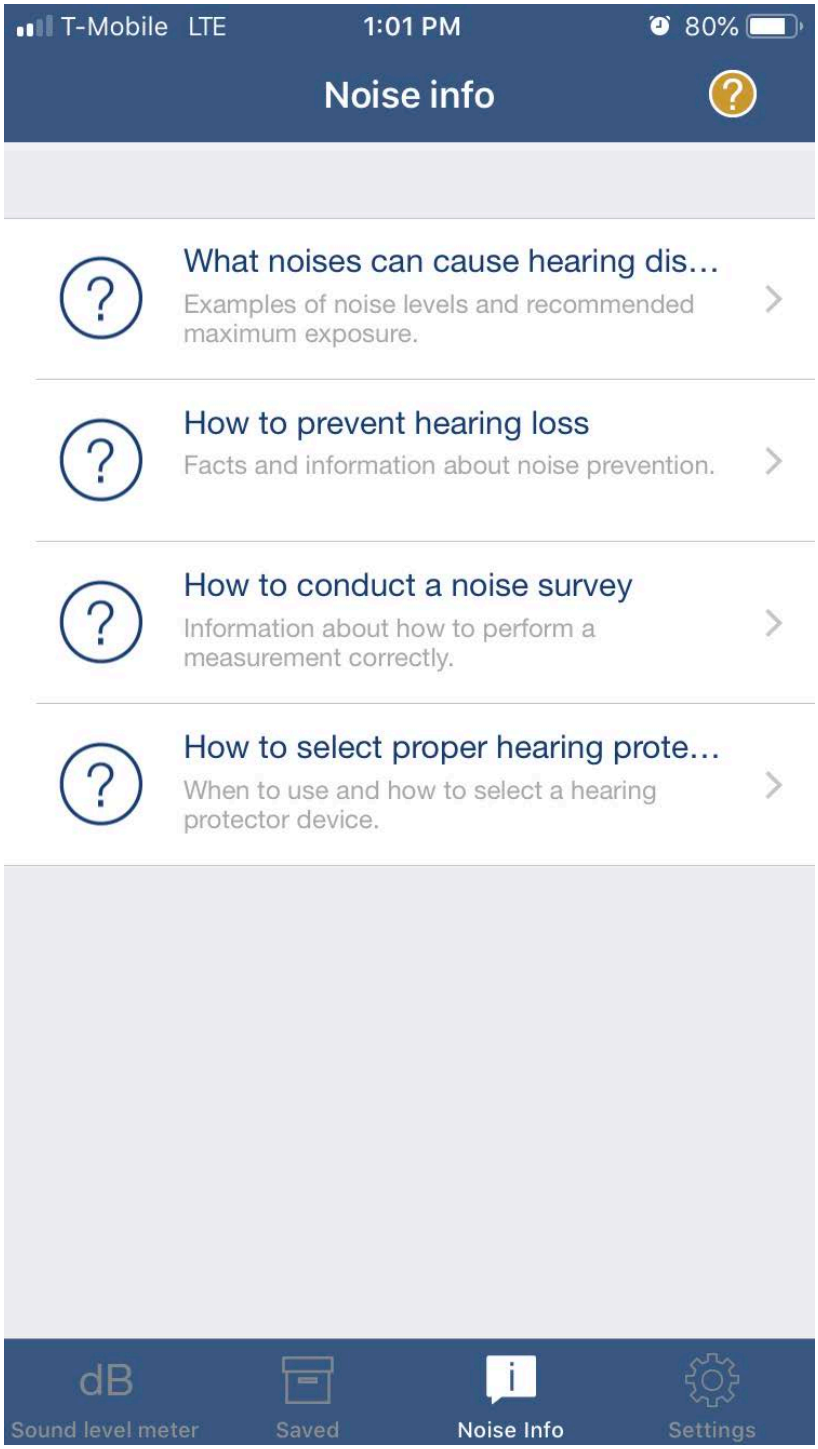


A detailed look at what the saved measurement contains, the report information (date, measurement time, operator, location) as well as the measured values from the mains screen.

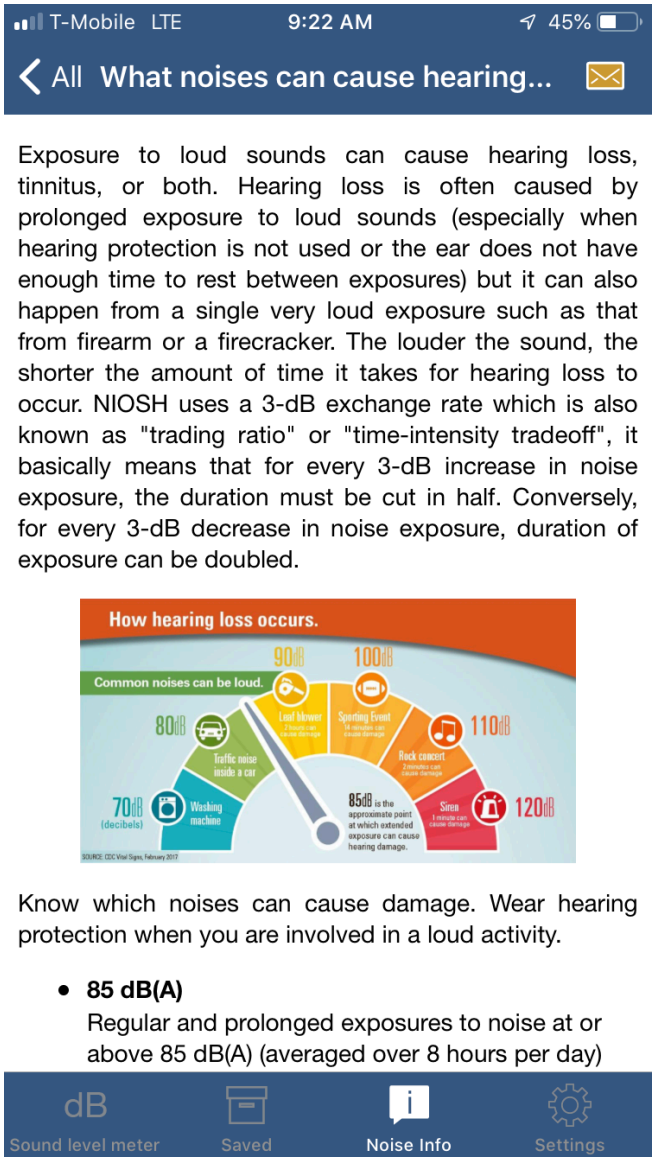


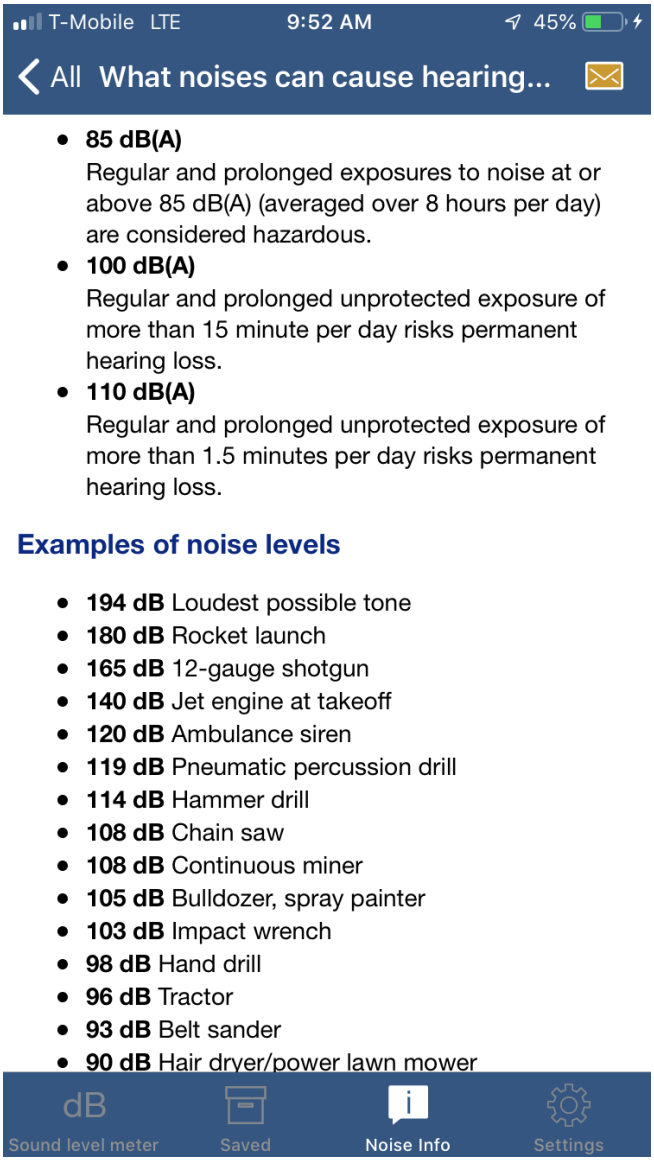
Noise info screen

The third screen contains basic information from the NIOSH Noise and Hearing Loss Prevention Program and other NIOSH research resources:

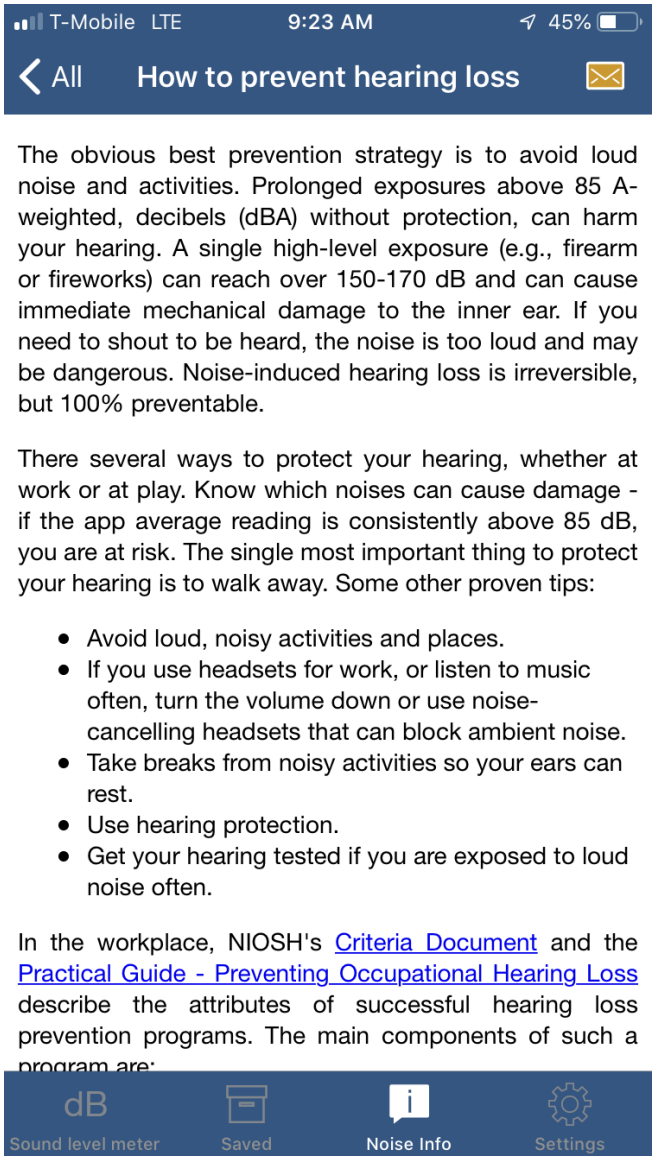


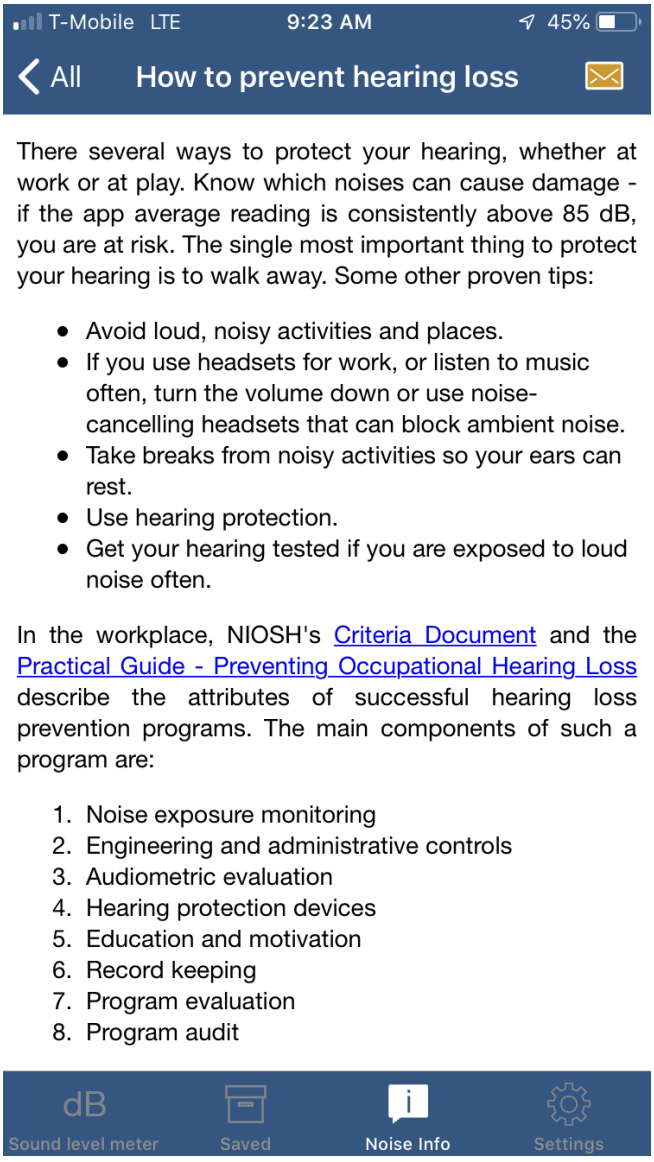
a. What noises can cause hearing disorders



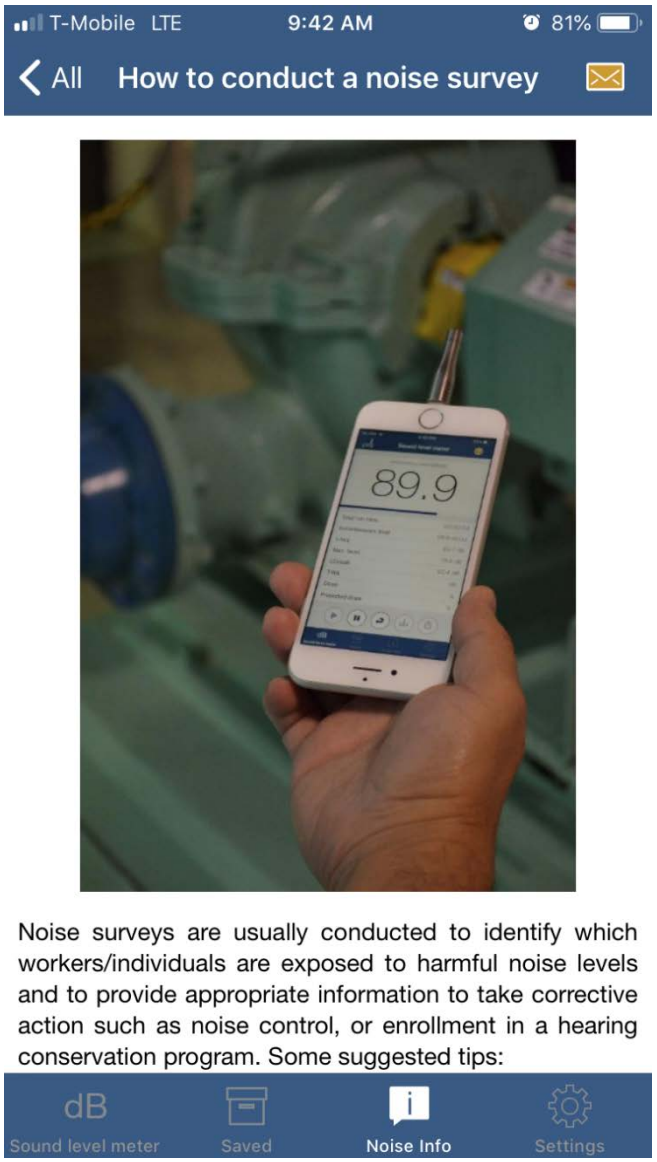


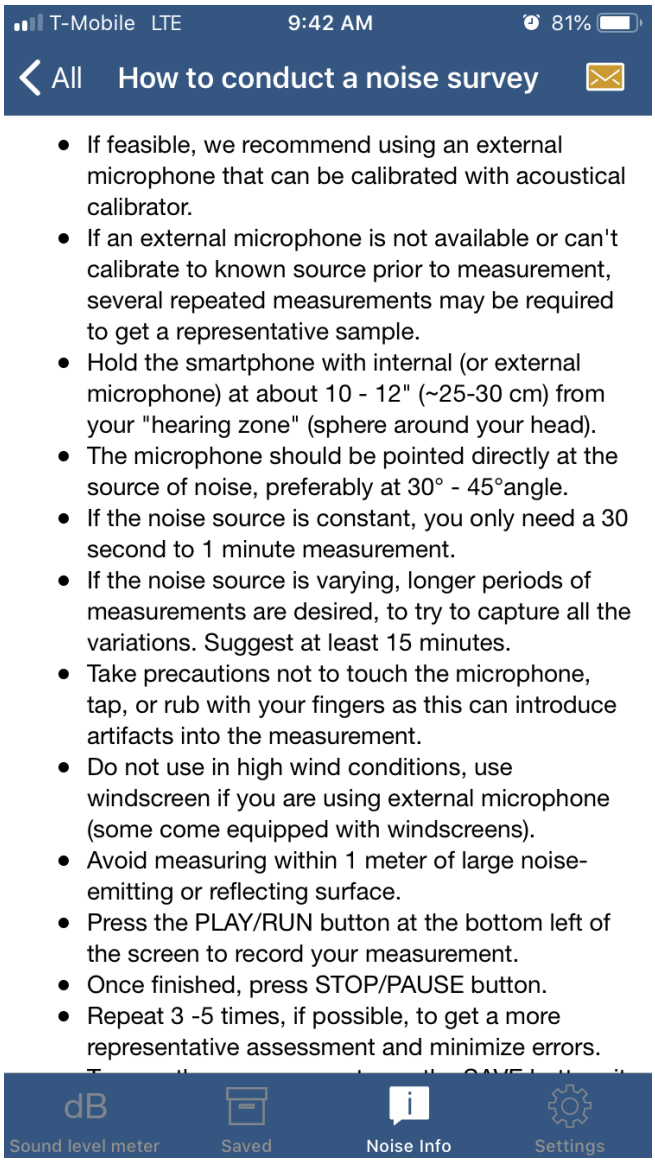
b. How to prevent hearing loss

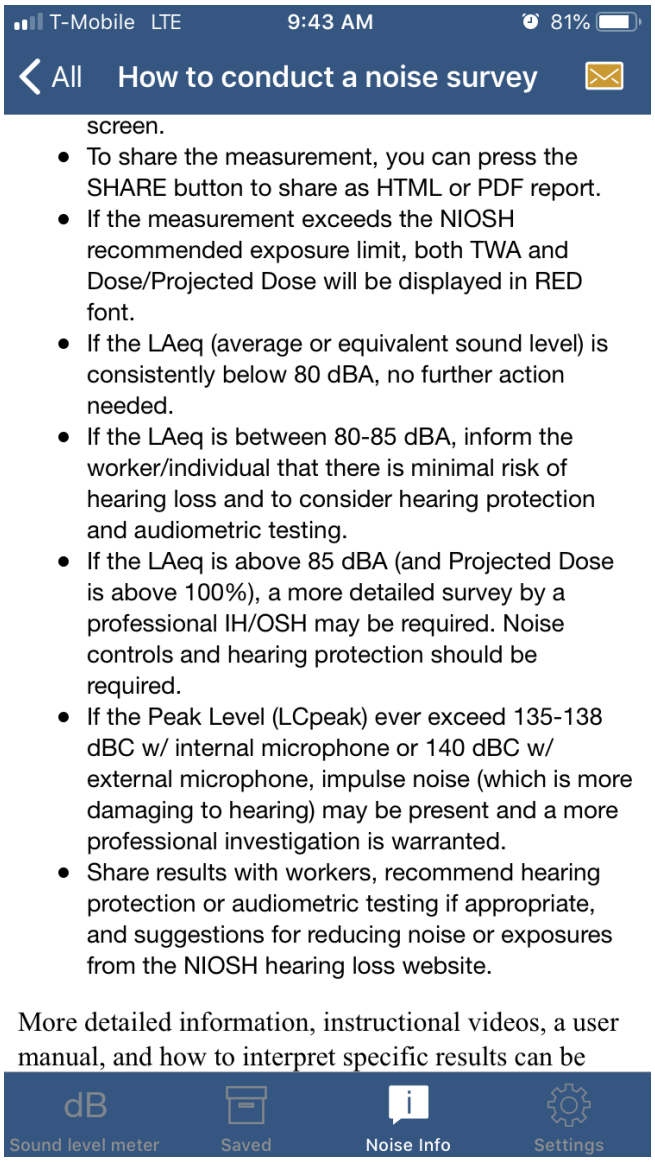


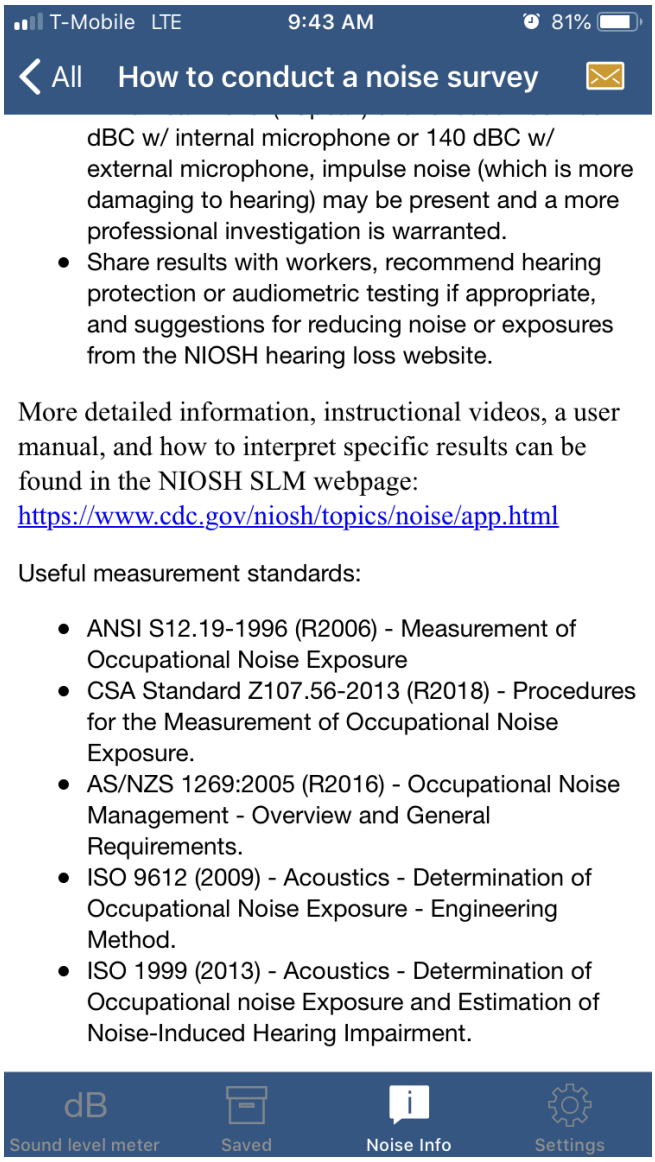


c. How to conduct a noise survey

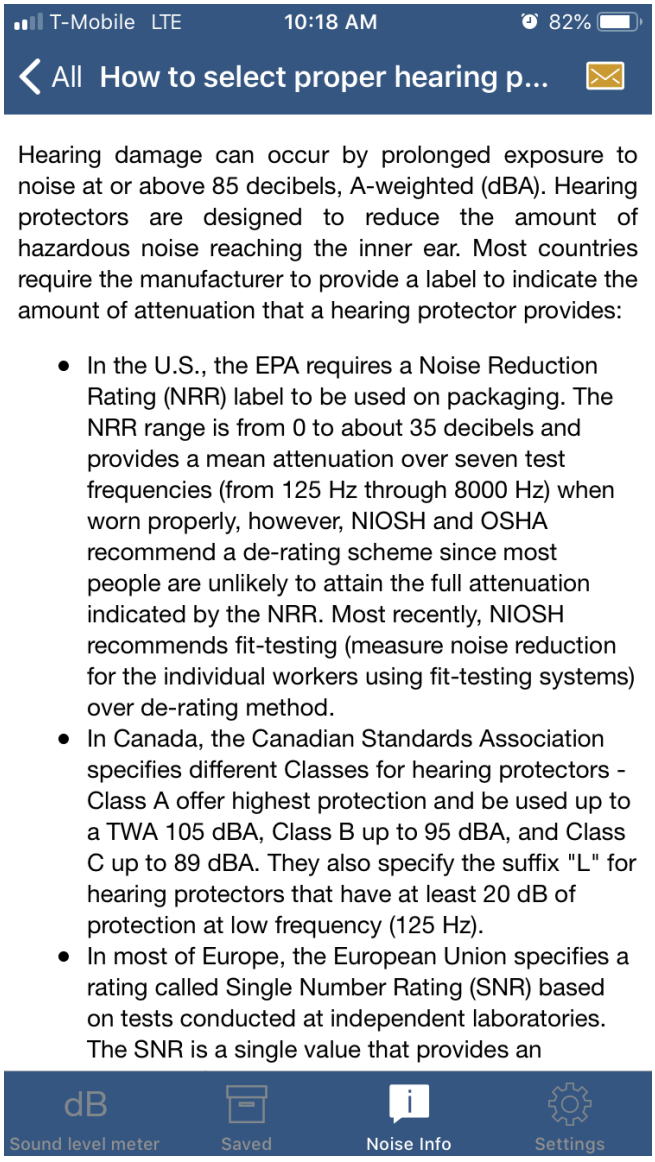


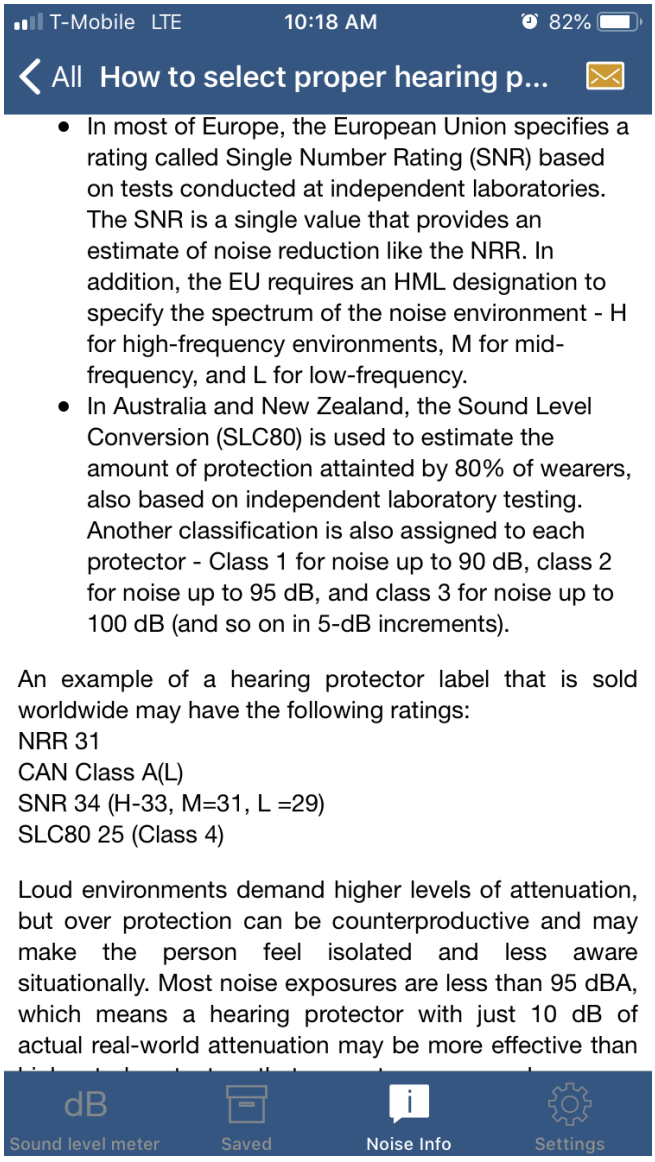


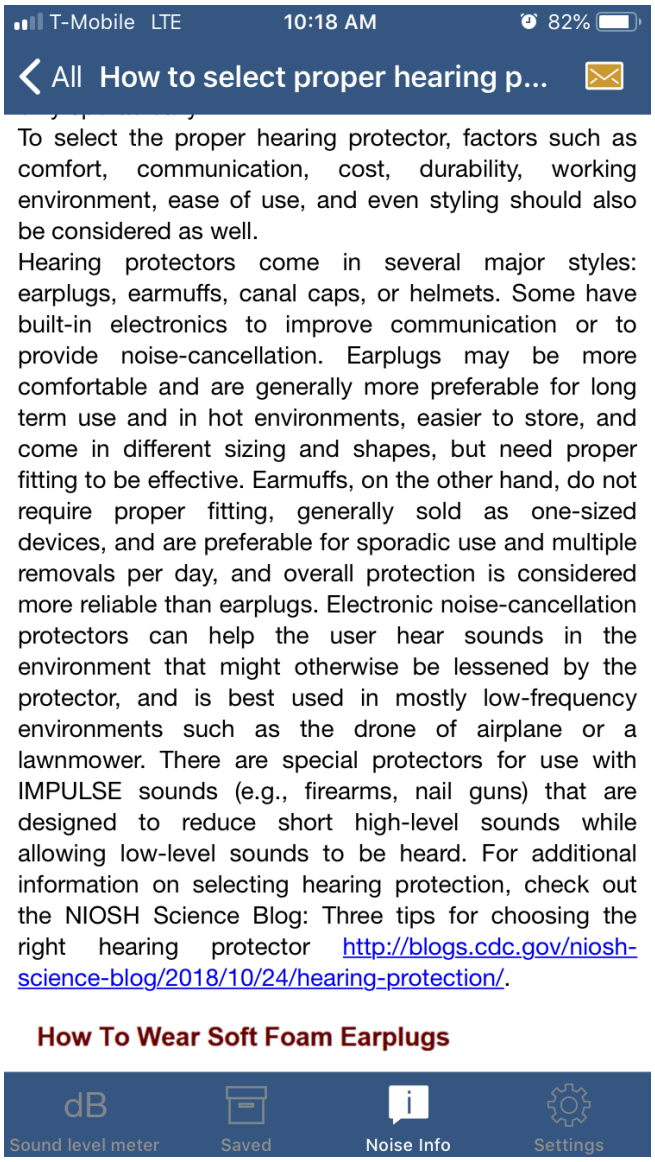

T-Mobile LTE 9:43 AM 81%
All How to conduct a noise survey
screen.
To share the measurement, you can press the SHARE button to share as HTML or PDF report.
If the measurement exceeds the NIOSH recommended exposure limit, both TWA and Dose/Projected Dose will be displayed in RED font.
If the LAeq (average or equivalent sound level) is consistently below 80 dBA, no further action needed.
If the LAeq is between 80-85 dBA, inform the worker/individual that there is minimal risk of hearing loss and to consider hearing protection and audiometric testing.
If the LAeq is above 85 dBA (and Projected Dose is above 100%), a more detailed survey by a professional IH/OSH may be required. Noise controls and hearing protection should be required.
If the Peak Level (LCpeak) ever exceed 135-138 dBC w/ internal microphone or 140 dBC w/ external microphone, impulse noise (which is more damaging to hearing) may be present and a more professional investigation is warranted.
Share results with workers, recommend hearing protection or audiometric testing if appropriate, and suggestions for reducing noise or exposures from the NIOSH hearing loss website.
More detailed information, instructional videos, a user manual, and how to interpret specific results can be
dB
Sound level meter
Saved
Noise Info
Settings

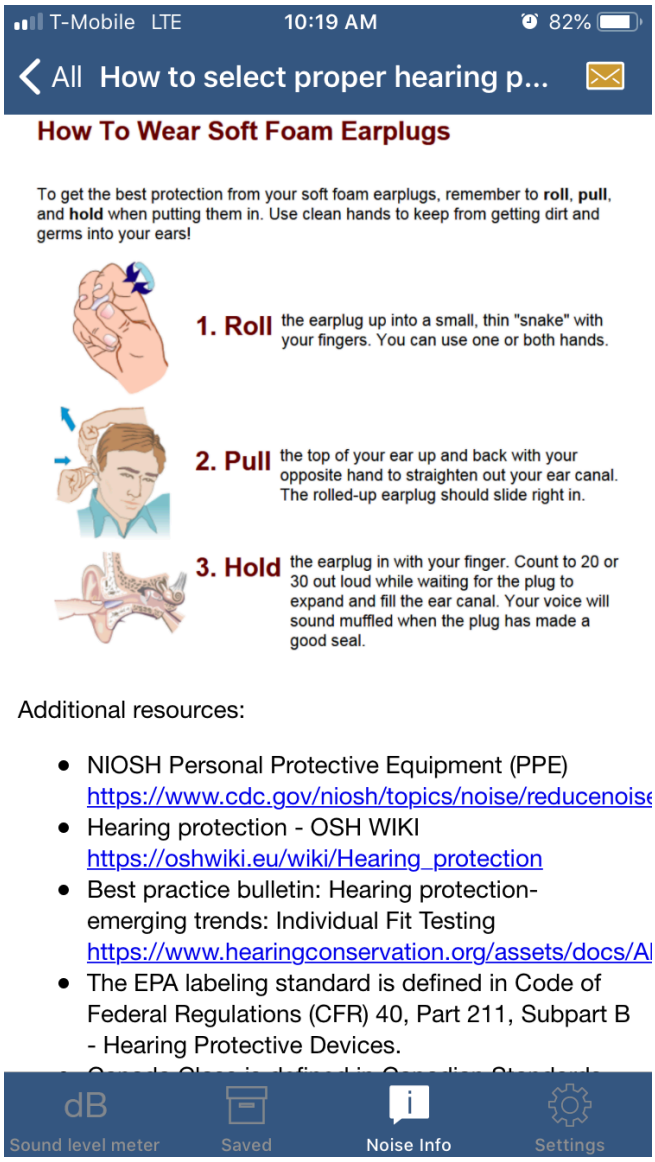

T-Mobile LTE 9:43 AM 81%
All How to conduct a noise survey
dBC w/ internal microphone or 140 dBC w/ external microphone, impulse noise (which is more damaging to hearing) may be present and a more professional investigation is warranted.
Share results with workers, recommend hearing protection or audiometric testing if appropriate, and suggestions for reducing noise or exposures from the NIOSH hearing loss website.
More detailed information, instructional videos, a user manual, and how to interpret specific results can be found in the NIOSH SLM webpage: https://www.cdc.gov/niosh/topics/noise/app.html
Useful measurement standards:
ANSI S12.19-1996 (R2006) - Measurement of Occupational Noise Exposure
CSA Standard Z107.56-2013 (R2018) - Procedures for the Measurement of Occupational Noise Exposure.
AS/NZS 1269:2005 (R2016) - Occupational Noise Management - Overview and General Requirements.
ISO 9612 (2009) - Acoustics - Determination of Occupational Noise Exposure - Engineering Method.
ISO 1999 (2013) - Acoustics - Determination of Occupational noise Exposure and Estimation of Noise-Induced Hearing Impairment.
dB
Sound level meter
Saved
Noise Info
Settings

d. How to select proper hearing protection

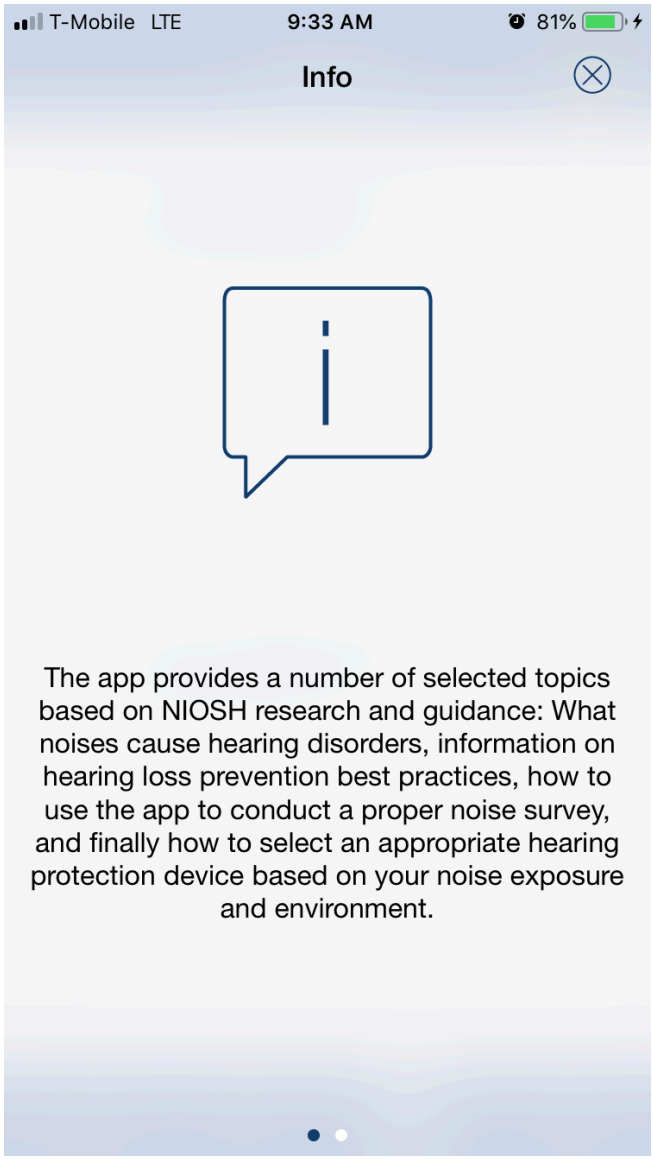


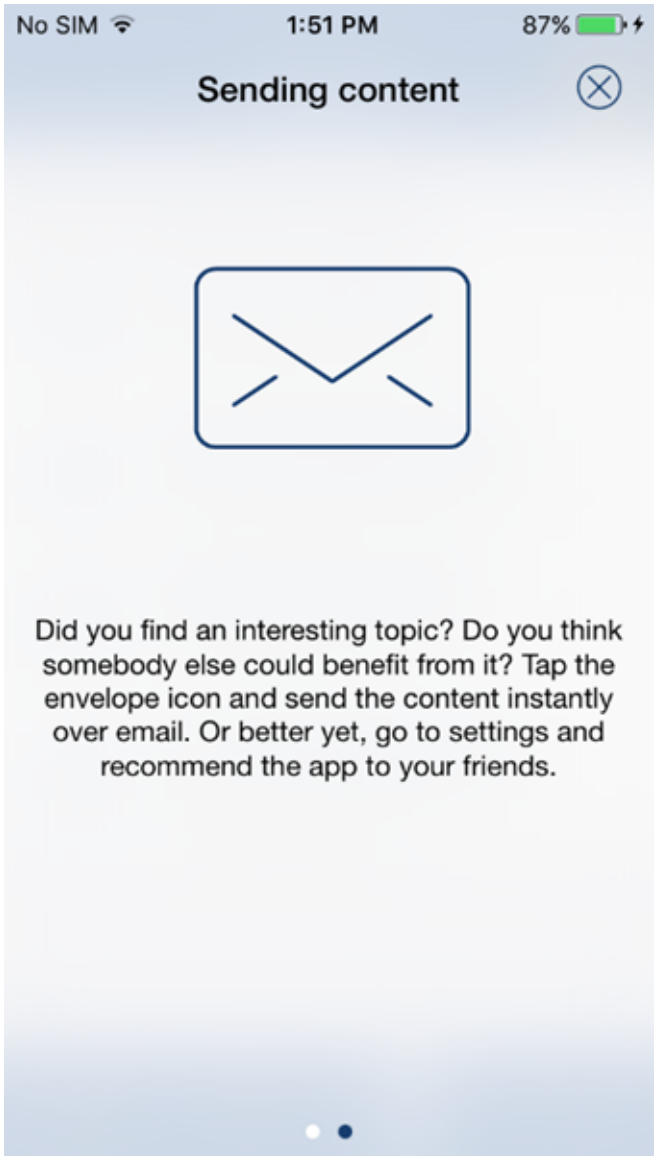



T-Mobile LTE 10:18 AM 82%
All How to select proper hearing p...
To select the proper hearing protector, factors such as comfort, communication, cost, durability, working environment, ease of use, and even styling should also be considered as well.
Hearing protectors come in several major styles: earplugs, earmuffs, canal caps, or helmets. Some have built-in electronics to improve communication or to provide noise-cancellation. Earplugs may be more comfortable and are generally more preferable for long term use and in hot environments, easier to store, and come in different sizing and shapes, but need proper fitting to be effective. Earmuffs, on the other hand, do not require proper fitting, generally sold as one-sized devices, and are preferable for sporadic use and multiple removals per day, and overall protection is considered more reliable than earplugs. Electronic noise-cancellation protectors can help the user hear sounds in the environment that might otherwise be lessened by the protector, and is best used in mostly low-frequency environments such as the drone of airplane or a lawnmower. There are special protectors for use with IMPULSE sounds (e.g., firearms, nail guns) that are designed to reduce short high-level sounds while allowing low-level sounds to be heard. For additional information on selecting hearing protection, check out the NIOSH Science Blog: Three tips for choosing the right hearing protector http://blogs.cdc.gov/niosh-science-blog/2018/10/24/hearing-protection/.
How To Wear Soft Foam Earplugs
dB
Sound level meter
Saved
Noise Info
Settings


T-Mobile LTE 10:19 AM 82%
All How to select proper hearing p...
How To Wear Soft Foam Earplugs
To get the best protection from your soft foam earplugs, remember to roll, pull, and hold when putting them in. Use clean hands to keep from getting dirt and germs into your ears!
1. Roll the earplug up into a small, thin "snake" with your fingers. You can use one or both hands.
2. Pull the top of your ear up and back with your opposite hand to straighten out your ear canal. The rolled-up earplug should slide right in.
3. Hold the earplug in with your finger. Count to 20 or 30 out loud while waiting for the plug to expand and fill the ear canal. Your voice will sound muffled when the plug has made a good seal.
Additional resources:
NIOSH Personal Protective Equipment (PPE) https://www.cdc.gov/niosh/topics/noise/reducenois
Hearing protection - OSH WIKI https://oshwiki.eu/wiki/Hearing_protection
Best practice bulletin: Hearing protection-emerging trends: Individual Fit Testing https://www.hearingconservation.org/assets/docs/A
The EPA labeling standard is defined in Code of Federal Regulations (CFR) 40, Part 211, Subpart B - Hearing Protective Devices.
dB
Sound level meter
Saved
Noise Info
Settings

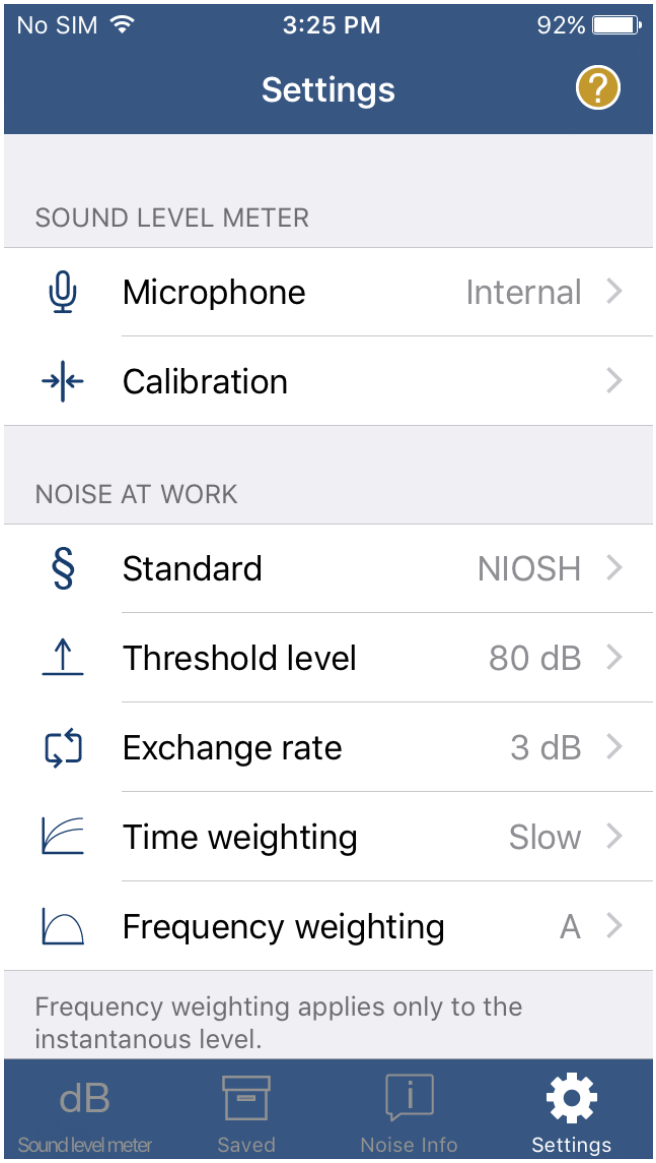
There are two “help” screens for such as for Info, and Sending content from the Noise info screens.

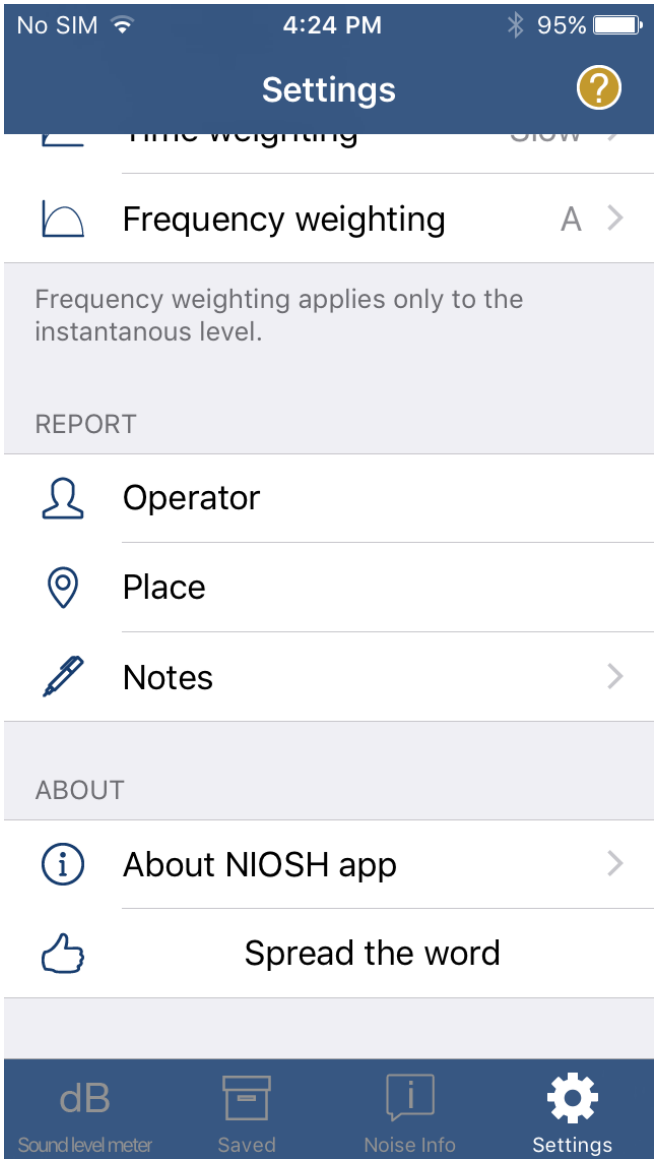




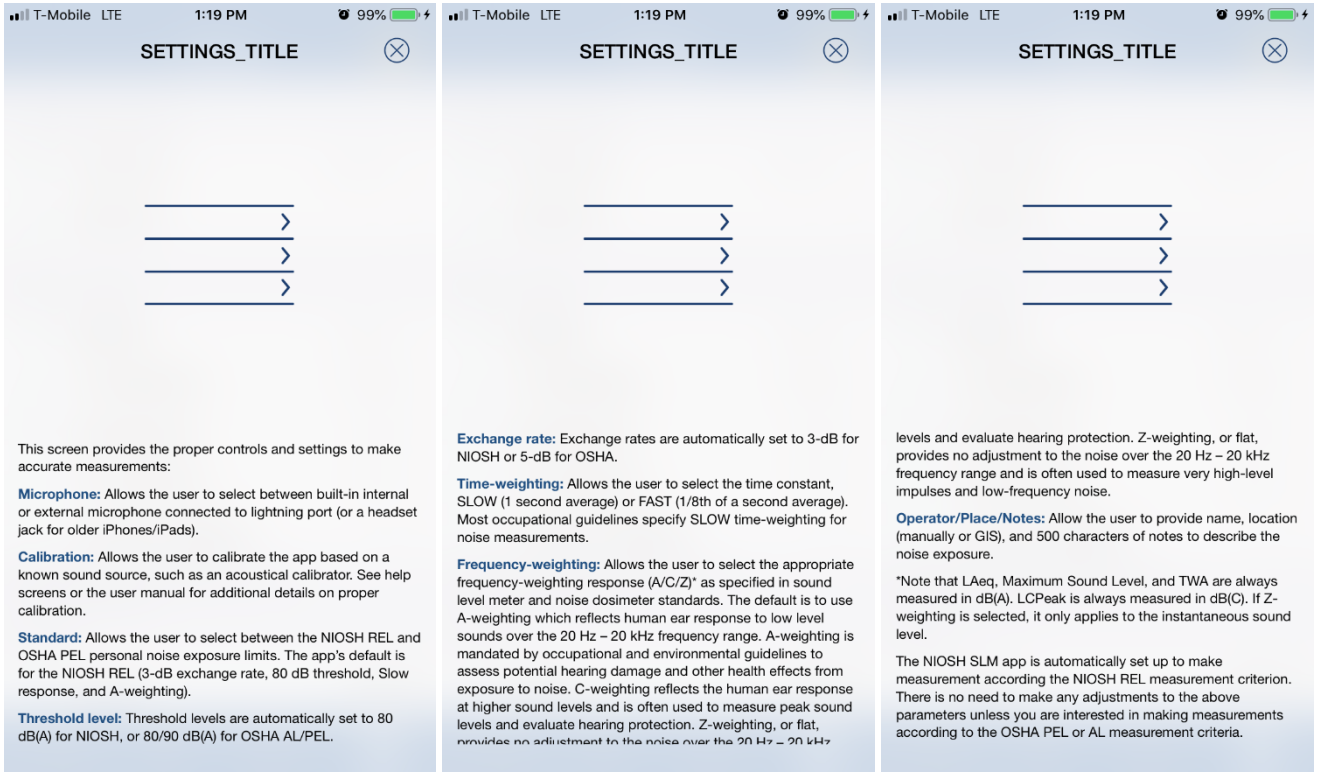
Settings Screen

The settings screen provides the user with the proper controls and settings to make accurate measurements.





There is a help screen for Settings that explains all the various parameters and what they mean:



Under **SOUND LEVEL METER**, there are two control settings:

1. Microphone: Allows the user to select between the built-in internal microphone or an external microphone connected to lightning port or a headset jack.

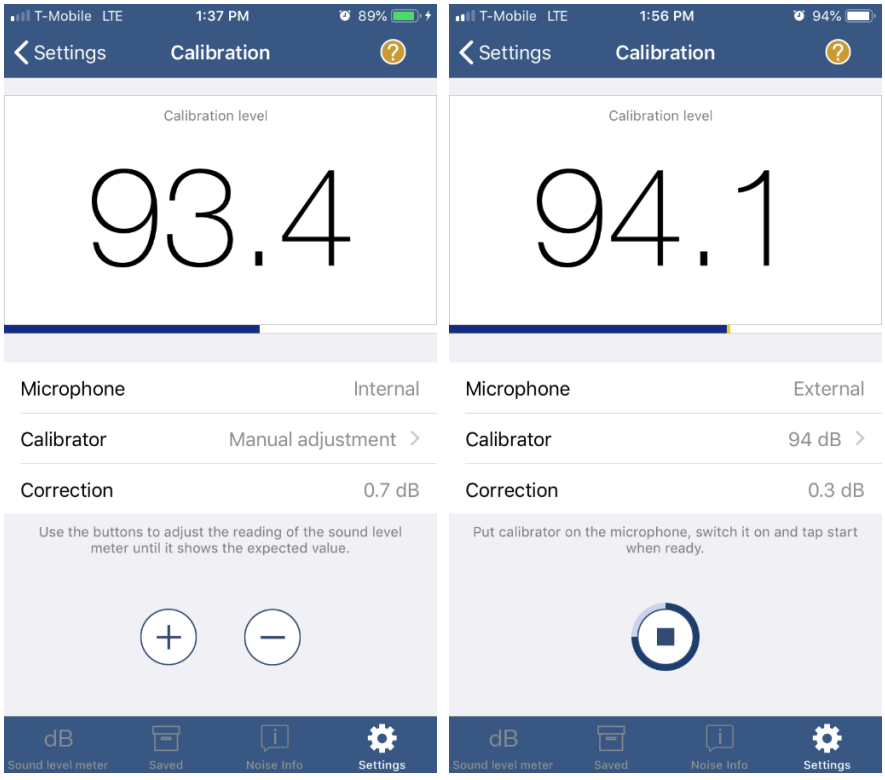
2. Calibration: Allows the user to calibrate the app before each use, either manually or automatically. The process of calibration is used to adjust the reading of the app (which might not be always correct because of differences in microphone sensitivity, effects of environmental conditions, or possible damage from mishandling or manufacturer defect) to match a known sound source. Calibration is recommended before and after each measurement. The app offers two forms of calibrations, manual (for internal microphones) and automatic (for external microphones):

    a. Manual Calibration:

    The user can manually adjust the reading on the calibration screen by pressing the plus (+) or minus (-) buttons on the screen to match the reading of a known reference, such as a calibrated sound level meter. The level can be adjusted in 0.1 dB increments.

    b. Automatic Calibration

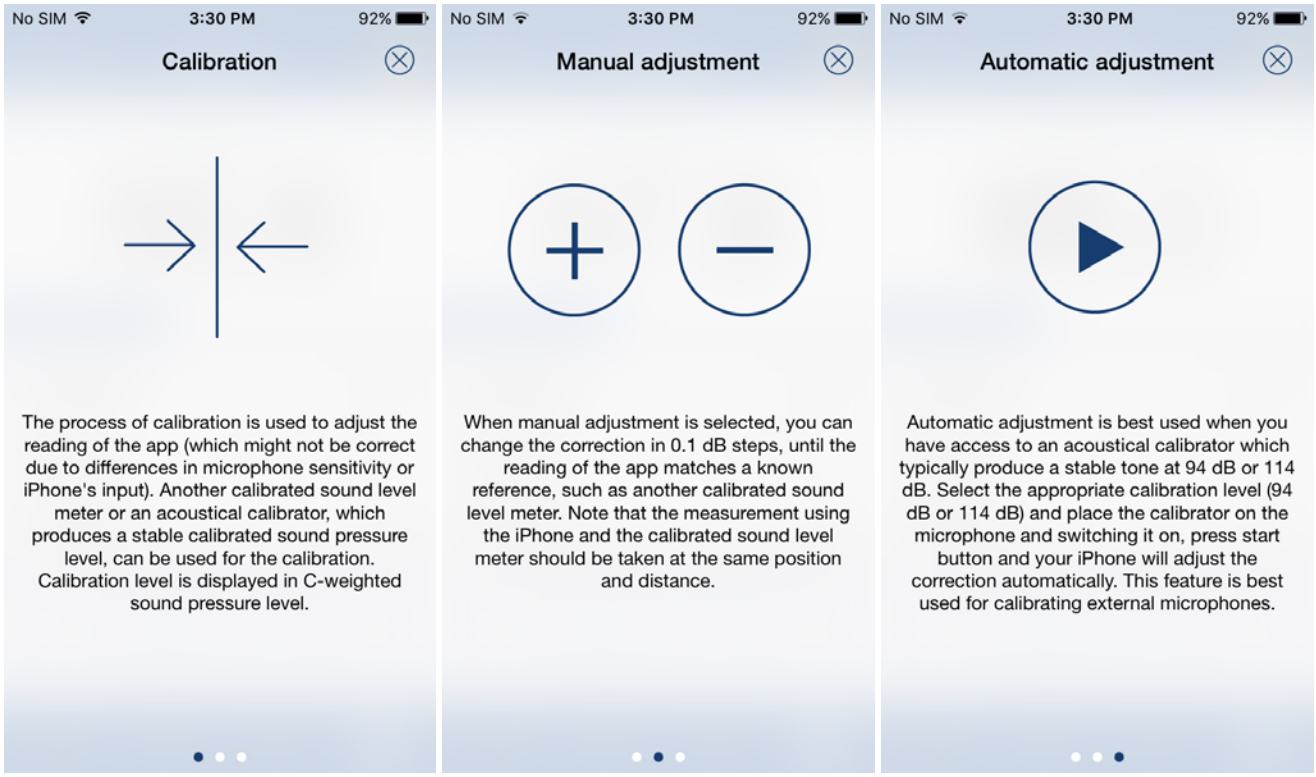
    The automatic adjustment feature is best used for calibrating the app with external microphones. This is an advanced feature aimed at more professional sound measurements since it requires access to an acoustical calibrator as well. The users places the acoustical calibrator on the microphone as shown, most acoustical calibrators can generate a calibration tone of 94 dB or 114 dB (sound pressure level). The user presses the Play button and the app will adjust the level automatically to either 94 dB or 114 dB.



The image below shows how to calibrate the app with an external microphone using an acoustical calibrator:

We also show how calibration is done with an external microphone in this informational video at the 4:04 mark: https://www.youtube.com/watch?v=zk07tLj_SDs

There are also three “help” screens that can guide the user in conducting an accurate calibration as shown below:



Occupational exposure standards were established to protect workers against the health effects of exposures to hazardous substances and agents when certain values (or limits) are reached. NIOSH established recommended exposure limits (RELs) on the basis of the best available science and practice. The REL for noise is 85 decibels, using the A-weighting frequency response and a 3-dB exchange rate as an 8-hour TWA; exposures at or above this level are considered hazardous. OSHA sets legally enforceable permissible exposure limits (PELs) that require employers to take actions to reduce worker exposures. The OSHA PEL for noise is 90 dB(A) as an 8-hr TWA based on a 5-dB exchange rate. NIOSH uses the 80 dB(A) threshold level for calculating the REL. OSHA uses a 90 dB(A) threshold for calculating the PEL and an 80 dB(A) threshold for calculating the Action level.

Under **NOISE AT WORK**, there are four settings:

1. Standard: Allows the user to select between NIOSH or OSHA measurement criteria.

2. Threshold level: Threshold levels are automatically set to 80 dB(A) for NIOSH, or 80/90 dB(A) for OSHA AL/PEL.

3. Exchange rate: Exchange rates are automatically set to 3-dB for NIOSH or 5-dB for OSHA.

4. Time weighting: Allows the user to select the time constant, SLOW (1 second average) or FAST (1/8th of a second average). Most occupational guidelines specify SLOW time-weighting for measurements.

5. Frequency weighting: Allows the user to select the appropriate frequency-weighting response (A/C/Z)* as specified in sound level meter and noise dosimeter standards. The default is to use A-weighting which reflects human ear response to low level sounds over the 20 Hz – 20 kHz frequency range. A-weighting is mandated by occupational and environmental guidelines to assess potential hearing damage and other health effects from exposure to noise. C-weighting reflects the human ear response at higher sound levels and is often used to measure peak sound levels and evaluate hearing protection. Z-weighting, or flat, provides no adjustment to the noise over the 20 Hz – 20 kHz frequency range and is often used to measure very high-level impulses and low-frequency noise.

*Note that LAeq, maximum sound level, and TWA are always measured in dB(A). LCPeak is always measured in dB(C). If Z-weighting is selected, it only applies to the instantaneous sound level.

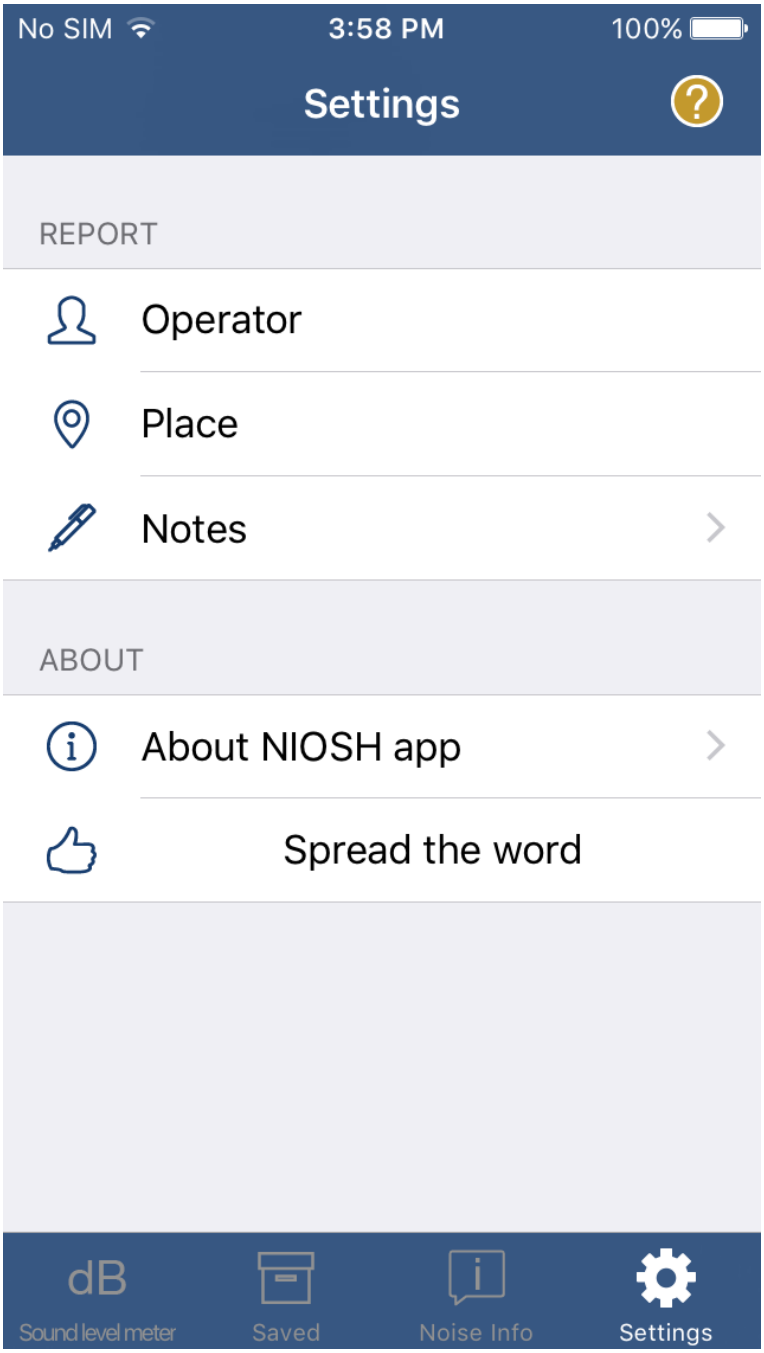
As mentioned, the NIOSH SLM app is automatically set up to make measurement according the NIOSH REL measurement criterion. There is no need to make any adjustments to the above parameters unless you are interested in making measurements according to the OSHA PEL or AL measurement criterion.

Under **REPORT**, there are three settings:

1. Operator: Allows the user to input the name or number related to the operator of the app.

2. Place: Allows the user to input the location of the measurement, which can either be typed in manually or automatically generated by selecting the GIS location icon to use the phone's location service.

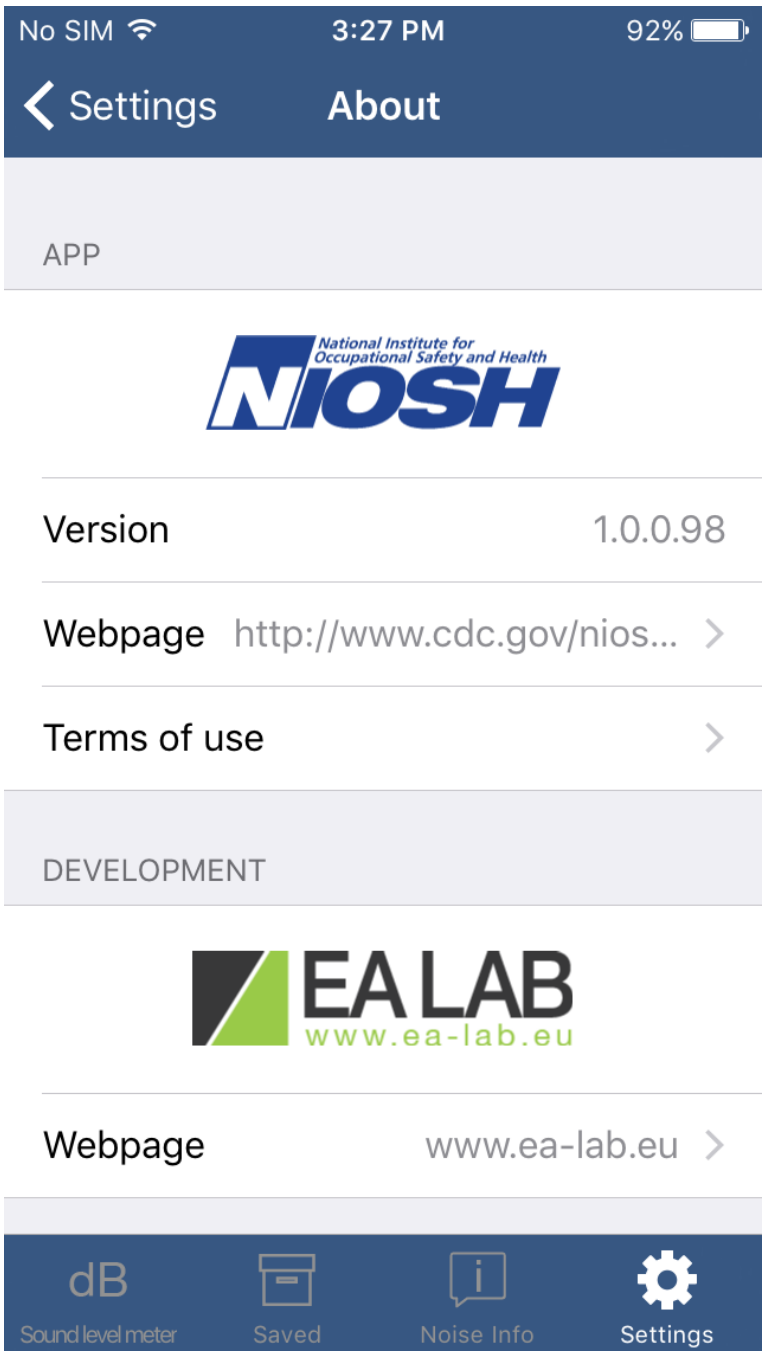
3. Notes: Allows the user to enter additional notes up to 500 characters related to the measurement.



Under **ABOUT**, there are two settings:

1. About NIOSH app (contains information about NIOSH, version, terms of use; and EA LAB - the developer of the app.

2. Spread the word: Allows the user to share the app via social media or email messaging platforms.



Relevant smartphone studies

Kardous and Shaw (2014). Evaluation of smartphone sound measurement applications – Journal of Acoustical Society of America.

Kardous and Shaw (2014). So how accurate are these smartphone sound measurement apps? – NIOSH Science Blog.

Kardous and Shaw (2016). Evaluation of smartphone sound measurement applications (apps) using external microphones – A follow-up study – Journal of Acoustical Society of America.

Roberts, Neitzel, and Kardous (2016). Improving the accuracy of smart devices to measure noise exposure – Journal of Occupational and Environmental Hygiene.

Kardous and Celestina (2017). New NIOSH Sound Level Meter App – NIOSH Science Blog.

Celestina, Hrovat, and Kardous (2018). Smartphone-based sound level measurement apps: Evaluation of compliance with international sound level meter standards – Applied Acoustics Journal.