A content analysis of behaviour change techniques in noise monitoring apps

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Abstract

Background: Exposure to excessive noise levels in occupational or recreational settings can be a hazard to hearing. Behaviour change techniques in noise monitoring apps have the potential to create a behavioural shift towards safer listening habits in the long-term.

Purpose: To assess the number of smartphone noise monitoring apps currently available, ascertain key features, and determine whether they contain techniques aimed at changing the user's behaviour in relation to noise exposure.

Method: Noise apps were searched on the Australian Apple App Store and Google Play Store. The search returned 499 unique apps, with 250 deemed as relevant noise apps. Apps were coded for key features and assessed for behaviour change techniques.

Results: Ninety-six percent of apps displayed the sound measurement result in decibels. Other common displays were a dial, bar, graph, loudness descriptor, and/or loudness chart. Colour was used to indicate different noise levels in 40% of apps. Nineteen percent (47 apps) incorporated behaviour change techniques. The three behaviour change techniques identified were 'feedback and monitoring' (45 apps), 'natural consequences' (17 apps), and 'shaping knowledge' (four apps). Two apps incorporated three behaviour change techniques, 15 apps incorporated two behaviour change techniques, and 30 apps incorporated one behaviour change technique.

Conclusion: Up to three behaviour change techniques were found in 19% of noise apps. Future research is needed to assess whether these behaviour change techniques are effective for a long-term shift towards safer listening behaviours.

Introduction

Exposure to excessive noise levels has been recognised as a hazard to hearing for at least 50 years when bell ringers were found to suffer from deafness arising from their occupation (Bruusgaard, 1962, as cited by Chadwik, 1973). Occupational noise exposure remains a cause for concern today. It is estimated that 22 million US workers are exposed to hazardous noise each year, and 24% of US workers' hearing difficulties are attributed to occupational exposure (National Institute for Occupational Safety and Health, 2019). In Australia, 19.5% of male workers and 2.8% of female workers are exposed to workplace noise levels that exceed the exposure limit of 85 dB L_{Aeq} over 8 hours (Lewkowski et al., 2019). Recreational noise sources are also identified as a risk, with the World Health Organization estimating that 1 billion young people worldwide are at risk of hearing loss due to unsafe listening practices. Nearly 50% of people aged 12-35 years in middle- and high-income countries are exposed to unsafe levels from the use of personal listening devices and around 40% are exposed to potentially damaging sound levels at clubs, discotheques, and bars (World Health Organization, 2015). Exposure to high noise levels can have negative impacts that are either auditory or non-auditory. Auditory effects include noise-induced hearing loss and tinnitus (ringing in the ears) (Basner et al., 2014); and non-auditory effects include increased risk of cardiovascular disease, reduced cognitive performance, and sleep disturbance (see Basner et al., 2014, for a review). Hearing loss has also been found to contribute to social isolation and is associated with anxiety, depression, lower self-esteem, and reduced wellbeing (Gates & Mills, 2005; Tambs, 2004).

Because in the past noise exposure was primarily encountered in the workplace, occupational noise exposure limits have been in place for decades as a way of controlling exposure and minimising the risk of long-term hearing damage. In Australia and many other jurisdictions, the workplace noise exposure limit is in line with the US National Institute for

Occupational Safety and Health (NIOSH) which recommends a noise exposure limit of “85 decibels, A-weighted, as an 8-hour time-weighted average (85 dB $L_{Aeq,8h}$) using a 3 dB exchange rate” (Berger, Royster, Royster, Driscoll, & Layne, 2000; National Institute for Occupational Safety and Health, 2018). The 3 dB exchange rate means that for every 3 dB increase in noise level, the exposure duration is halved, as shown in Table 1[1].

Table 1: 3 dB exchange rate for noise exposure limits

Noise Level (dB L_{Aeq})	Daily Exposure Limit
85	8 hours
88	4 hours
91	2 hours
94	1 hour
97	30 min
100	15 min

Occupational noise exposure is calculated over a 5-day week, but recreational exposures can occur at any time and are not restricted to typical work patterns, which assume 8-hour work shifts from Monday to Friday. As yet there is no consensus on an appropriate

[1] Note that the US Occupational Safety and Health Administration (OSHA) has a different recommendation. OSHA’s permissible exposure limit is 90 dBA for an 8 hour day with a 5 dB exchange rate (Occupational Safety and Health Administration, 2001).

damage-risk criterion for recreational noise exposures. The World Health Organisation (WHO) and the International Telecommunication Union (ITU) recently devised a standard for exposure to sound from personal listening devices. The standard recommends that an adult's exposure should not exceed 80 dBA for 40 hours over a 7-day week with a 3 dB exchange rate as shown in Table 2 (World Health Organization and International Telecommunication Union, 2019). In their recent review, Neitzel and Fligor (2019) recommended three possible exposure limits for recreational sound. The most conservative limit that would eliminate the risk of noise-induced hearing loss was 70 dBA L_{eq24h} which is equivalent to a 75 dBA L_{EX}. This includes a margin of safety to account for vulnerable individuals or those who are more susceptible to noise-induced damage. The second possible exposure limit was 75 dBA L_{eq24h} which is equivalent to 80 dBA L_{EX}. This limit should nearly eliminate the risk of developing a noise-induced hearing loss over a 40-year working lifetime. They note, however, that because exposures to music and noise may be greater than 40 years, this "represents an optimal trade-off between being sufficiently protective and being onerous and/or technically or socially infeasible". Their third alternative proposal was 78 dBA L_{eq24h} which is equivalent to 83 dB L_{EX}. The authors describe this as a liberal recommended exposure limit with modest risk for noise-induced hearing loss, but sufficient to protect most people exposed to non-occupational music.

Table 2: Noise exposure limits for personal listening devices outlined by WHO-ITU.

Noise Level (dBA)	Weekly Exposure Limit
80	40 hours
83	20 hours
86	10 hours
89	5 hours
92	2.5 hours
95	75 mins

In workplaces where noise levels are of concern, occupational hygienists or health and safety officers monitor exposure using a sound level meter or body-worn dosimeters, which are expensive and specialised pieces of equipment. If noise levels are above the exposure standard, employers are legally obliged to implement measures to reduce or eliminate the source of the noise. If this is not possible, other steps can be taken, such as limiting the amount of time an employee spends in the noisy environment, and providing employees with personal protective equipment such as earmuffs or earplugs.

In recreational settings, such as bars and clubs, sound levels are not subjected to the same level of oversight even though they can be just as loud (if not louder) than many noisy workplaces. Many individuals are unaware of the potential risk associated with these environments, and very few take steps to protect themselves or reduce their level of exposure. However, the development of the smartphone, with its inbuilt microphone and increasingly sophisticated apps, means that individuals can now measure their noise exposure using a device that they already own.

Kardous and Shaw (2014) evaluated the accuracy of 14 smartphone sound measurement apps and found that the performance of three Apple apps was within ±2 dBA of the reference value. The authors concluded that certain sound measurement apps for Apple smartphones and tablets were sufficiently accurate to be used to measure noise levels, however, Android and Windows apps do not meet the functional requirements needed for occupational noise assessments due to high variance in measurements between devices.

Smartphone use is growing with an estimated 3.2 billion people worldwide owning a smartphone (Holst, 2019), which presents an unprecedented opportunity for vast numbers of people to measure their own sound levels and understand the associated level of risk. Since the Kardous and Shaw (2014) paper was published, noise apps have moved beyond the smartphone, with Apple releasing a noise app on its watch device in 2019. This app measures the sound levels in the environment and alerts the user when it reaches the level specified by the WHO-ITU guidelines.

While apps that measure sound levels enable individuals to identify when they are at risk of hazardous noise exposure, those that incorporate behaviour change techniques (in addition to sound level monitoring) have the potential to create a behavioural shift towards safer listening habits in the long-term. A behaviour change technique is defined as

> “an observable, replicable, and irreducible component of an intervention designed to alter or redirect causal processes that regulate behaviour; that is, a technique is proposed to be an ‘active ingredient’ (e.g., feedback, self-monitoring, and reinforcement)” (Michie et al., 2013, pg 82).

Incorporating behaviour change techniques in sound measurement apps designed for recreational noise exposure would have particular value because the largely unregulated nature of these environments means that individuals are responsible for managing their exposure and need support to understand when and how to mitigate their risk.

In 2013, Michie et al. published a structured taxonomy of 16 behaviour change technique groups that are used in health behaviour change interventions. The taxonomy was developed to guide the development of effective health behaviour interventions; to help promote accurate replication and implementation of interventions; and to support researchers investigating the efficacy of different behaviour change mechanisms (Michie et al., 2013). The behaviour change technique groups are: 1) scheduled consequences, 2) reward and threat, 3) repetition and substitution, 4) antecedents, 5) associations, 6) covert learning, 7) natural consequences, 8) feedback and monitoring, 9) goals and planning, 10) social support, 11) comparison of behaviour, 12) self-belief, 13) comparison of outcomes, 14) identity, 15) shaping knowledge, and 16) regulation. For example, the ‘feedback and monitoring’ group includes feedback on behaviour, biofeedback, and self-monitoring of behaviour. An example of this in a noise app could be an alarm that sounds when a particular noise exposure time has been reached. The ‘natural consequences’ group includes health consequences, social and environmental consequences, emotional consequences, and anticipated regret (i.e. experiencing the regret we might feel in the future around a decision that is about to be made). In a noise app, this might be incorporated by including the damage that noise can cause on the auditory system. The ‘shaping knowledge’ group includes reattribution, antecedents, behavioural experiments, and instruction on how to perform a behaviour. An example of this in a noise app could be information on how to insert earplugs.

The Michie taxonomy has been used to assess the use of behaviour change techniques in a range of health-related apps. In a 2015 study of apps that aimed to reduce problematic alcohol consumption, Crane, Garnett, Brown, West, and Michie (2015) found that only 14% of alcohol-related apps were focused on encouraging healthy drinking habits. Of these, there was a mean of 3.6 behaviour change techniques per app. The most common behaviour change techniques were 'facilitate self-recording' (feedback and monitoring), 'provide information on consequences of excessive alcohol use and drinking cessation' (natural consequences), 'provide feedback on performance' (feedback and monitoring), 'give options for additional and later support' (social support), and 'offer/direct towards appropriate written materials' (shaping knowledge). Five apps were found to contain more than 10 behaviour change techniques, although three of them only provided information for the user to read passively, rather than engage with actively. Crane et al. (2015) noted that inclusion of a greater number of behaviour change techniques does not necessarily mean the apps were more effective, citing mixed results in the relationship between number of behaviour change techniques and actual behaviour change outcomes (Dombrowski et al., 2012; Michie, Jochelson, Markham, & Bridle, 2009; Webb, Joseph, Yardley, & Michie, 2010).

Behaviour change techniques in apps designed to increase physical activity have also been assessed. Conroy, Yang, and Maher (2014) assessed the behaviour change techniques in physical activity apps using a taxonomy developed specifically for physical activity and healthy eating (Michie et al., 2011). They found fewer than four behaviour change techniques in most of the apps assessed. The most common behaviour change techniques were 'instruction on how to perform exercises' (shaping knowledge), 'modelling how to perform exercises' (comparison of behaviour), 'providing feedback on performance' (feedback and monitoring), 'goal-setting for physical activity' (goals and planning), and 'planning social support/change' (social support). They concluded that people may need to use multiple apps for behaviour change to be initiated and maintained in the longer term.

The aim of the current study was to assess the number of smartphone noise apps currently available, ascertain their key features, and determine whether they contain any of the behaviour change techniques defined by Michie et al. (2013). Noise apps were searched on the Australian Apple App Store and Google Play Store, screened for relevance, coded for key features, and assessed for behaviour change techniques.

Materials and Methods

A search for noise apps that measure and/or monitor the noise level of an environment was conducted on the Australian Apple App Store and Google Play Store in October-November 2019. Two search terms were used: ‘sound level’ and ‘noise meter’. As shown in Figure 1, a total of 670 apps were returned from the search. In the Apple App Store, 84 apps were returned under ‘sound level’ and 86 were returned for ‘noise meter’. For the Google Play Store, 250 apps were returned under ‘sound level’ and 250[2] were returned for ‘noise meter’. Duplicate apps that appeared in the results from both search terms were removed leaving 123 Apple apps and 382 Google Play apps. Six apps appeared in the search results for both Apple and Google Play, so these apps were only counted under Apple apps, leaving 376 Google Play apps. In all, there was a total of 499 noise apps included in the assessment.

First, all apps were screened for relevance. Twenty-five Apple apps and 221 Google Play apps were deemed irrelevant because they did not measure noise level. These apps included music equalizers, volume boosters, spirit levels, and games. After these were removed, this left a total of 253 apps: 98 Apple apps and 155 Google Play apps. Of these, a further three were excluded because they were removed from the app store during the period

[2] Note that a maximum of 250 apps are returned on the Google Play store search.

between the initial search and the assessment, resulting in a final set of 250 apps. The data collected for each app included the app name, developer, search order ranking (i.e. relevance), price, user rating, date of last update, device compatibility, description, display style used for presenting noise level information (e.g., dial, graph, etc.), and number of behaviour change techniques included in the app. The data were obtained by reading the description and assessing the screenshots provided by developers on the app store. If insufficient information was available, the app was downloaded by author 1 for further assessment. Ten percent of the apps were also assessed by author 2. Any discrepancies between the authors were discussed and resolved.

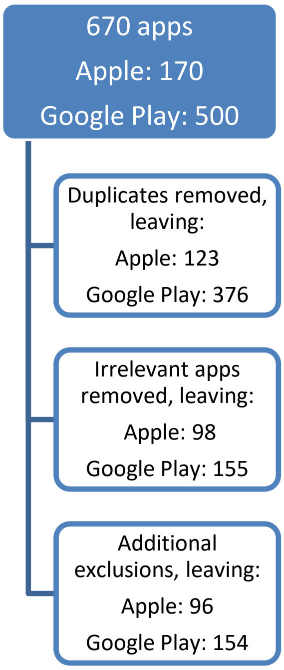

Figure 1: Flowchart of app selection for coding.

Results

Of the 250 apps assessed, 76% were free, a further 8% were free but included in-app purchases for additional features, and 17% required payment. The cost of the paid apps ranged from AUD$1.29 - AUD$30.99, and the mean price was AUD$6.75. One hundred and forty-five apps showed an average user star rating. Of these, 74% had four stars, 15% had 3 stars, 8% two stars, 2% had a rating of one star – only 1% had received five stars. Seventy-two percent of apps had been updated within the last two years. All of the Apple apps were compatible with iPhone, iPad, and iPod touch, and 16 (17%) were compatible with the Apple watch.

App Display

When displaying the measured sound level, the vast majority of apps (96%) showed the numerical result in decibels, 57% displayed the result on a graph, 50% indicated the number on a dial, 23% showed the sound level as progressive bar, 18% included a text-based loudness descriptor indicating a sound source with an equivalent sound level (e.g. rustling leaves for 35 dB, motorcycle for 90 dB), 12% displayed the sound level on a loudness chart showing the noise levels of common sound sources, and 40% used colour as an indication of the noise level (e.g. green when the noise level was < 65 dB, orange when it was 65-100 dB, and red when it was > 100 dB). Of the 10 apps that did not show the decibel as a number, five simply displayed a coloured dial with no numbers, four displayed a coloured bar with decibels marked in steps, and one displayed a dial with the noise level indicated in 10 dB steps.

Behaviour Change Techniques

Nineteen percent (n = 47) of the apps reviewed incorporated at least one behaviour change technique. Forty-five apps featured ‘feedback and monitoring’, 17 apps incorporated ‘natural consequences’, and four apps incorporated ‘shaping knowledge’. Two apps incorporated all three behaviour change techniques, 15 apps incorporated two behaviour change techniques, and 30 apps included only one behaviour change technique. The data are shown in Table 3.

Table 3: Behaviour change techniques in the apps.

App	Developer	Behaviour Change Technique			Description	Colour
		Feedback and Monitoring	Natural Consequences	Shaping Knowledge		
NIOSH Sound Level Meter	EA LAB	✓	✓	✓	• F&M – Dose: Noise dose of the user as a percentage of the maximum recommended occupational noise exposure over a day. • NC – Information: Explains NIOSH 3 dB time-intensity trade-off and gives examples of hazardous exposures, e.g., 85 dB averaged over 8 hours per day; 100 dB for more than 15 mins per day; 110 dB for more than 1.5 mins per day. • SK – Information: How to prevent hearing loss, how to select proper hearing protection devices, including how to insert earplugs, and how to conduct a noise survey.	No
SmarterNoise - video sound meter recorder camera	Agibili	✓	✓	✓	• F&M – Icons: Indicate if the user is at risk of experiencing the adverse effects of noise exposure in terms of annoyance, cognition, health, and hearing at the current noise level. • NC & SK – Information: Effects of noise annoyance, noise and cognition, noise and health risk, and noise and hearing health risk and at what noise level each of these occur.	No
Decibel Meter -	Dominic Watson		✓	✓	• NC & SK – Information: Text about noise-	Yes

Measure the sound around you with ease					induced hearing loss which can be caused by sounds over 85 dB.	
Noise Exposure	Arbetsmiljöverket		✓	✓	• NC & SK – Information: General information about the effects of noise but no indication of the decibel levels at which these effects occur.	Yes
Sound Meter:decibel meter,whisper & noise detector	Creative gigs	✓	✓		• F&M & NC – Hazard chart: 50+ dB affects rest and sleep, 70+ dB can affect learning and work, 90+ dB affects audition, and 150 dB will break the eardrum and audition will be completely lost.	No
Sound Meter:decibel meter,whisper & noise detector	Info Stack	✓	✓		• F&M & NC – Hazard chart: 50+ dB affects rest and sleep, 70+ dB can affect learning and work, 90+ dB affects audition, and 150 dB will break the eardrum and audition will be completely lost.	No
Sound Meter - Sound Measure	Manya Technology	✓	✓		• F&M & NC – Hazard chart: 50+ dB affects rest and sleep, 70+ dB can affect learning and work, 90+ dB affects audition, and 150 dB will break the eardrum and audition will be completely lost.	Yes
Decibel Meter- Noise Detector & Sound Meter	Grounders	✓	✓		• F&M & NC – Hazard chart: 50+ dB affects rest and sleep, 70+ dB can affect learning and work, 90+ dB affects audition, and 150 dB will break the eardrum and audition will be completely lost.	Yes
Sound Meter – Measure Noise DB (Analog & Digital)	InventiveStudio	✓	✓		• F&M & NC – Hazard chart: 50+ dB affects rest and sleep, 70+ dB can affect learning and work, 90+ dB affects audition, and 150 dB will break the eardrum and audition will be completely lost.	Yes
Sound Meter Decibles Pro	SoftClickSolutions	✓	✓		• F&M & NC – Hazard chart: 50+ dB affects rest and sleep, 70+ dB can affect learning and work,	No

				90+ dB affects audition, and 150 dB will break the eardrum and audition will be completely lost.	
My Decibel Meter-Free	Hongwen Yang	✓	✓	• F&M & NC – Hazard chart: 70 dB = annoying, 80 dB = possible hearing damage (8 hours), 90 dB = hearing damage (8 hours), 100 dB = serious hearing damage (8 hours), 110 = serious hearing damage (1 hour).	No
Noise Control Pro	Marcelo Lopes	✓	✓	• F&M & NC – Hazard chart: 70 dB = annoying, 80 dB = possible hearing damage, 90 dB = hearing damage (8 hours), 100 dB = serious hearing damage (8 hours), 110 = serious hearing damage (1 hour), 120 = human pain threshold	Yes
Sound Meter	Beacon Studio	✓	✓	• F&M & NC – Hazard chart: 60-70 dB disturbs normal rest and distracts people, 70-90 dB damages nerve cells making people's ears uncomfortable, 90-100 dB can cause hearing loss and ear pain, and 100-120 dB causes deafness in the ears which can lead to death.	Yes
Sound Meter+ (Ad Free)	Grace Jo	✓	✓	• F&M & NC – Nerve damage alert: When noise is over 70 dB says it may hurt the nerve and cause nerve damage when over 80 dB.	Yes
Sound Meter Simple(YC)	Grace Jo	✓	✓	• F&M & NC – Nerve damage alert: When noise is over 70 dB says it may hurt the nerve and cause nerve damage when over 80 dB.	Yes
Sound Meter Simple Detector	Grace Jo	✓	✓	• F&M & NC – Nerve damage alert: When noise is over 70 dB says it may hurt the nerve and cause nerve damage when over 80 dB.	Yes
Sound Level -	Slava Barouline	✓	✓	• F&M & NC – Warning if the noise level	No

Audio System dB, Home Theatre SPL				exposure may result in hearing loss.	
Sound Meter - Decibel Noise Detector	Android Simple App Stu	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	No
Noise Killer – Stop the Noise !	Apanza	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	No
Decibel Alert Lite	Nemo Xis	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	Yes
Sound and Noise Detector	RZTech	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	No
Sound Meter	JWK COOL	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	No
Noise Moderator	Sprint Coder	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	Yes
Noise Alert	Your Dev	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	No
Sound Meter	Trajkovski Labs	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	No
EZ Noise - Sound level meter with alarm	Boyma	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	No
Sound Meter	momogogo	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	Yes

Sound Meter	Mr Drew	✓		• F&M – Alert: Alarm sounds when the noise level set by the user is reached.	No
Decibel Meter Master	Yanhui Feng	✓		• F&M – Harmful level indicators: Coloured bar indicates whether the noise level is potentially harmful, dangerous, or very dangerous.	Yes
Decibel - Accurate dB Meter	Xiangyi Liu	✓		• F&M – Harmful level indicators: Coloured bar indicates whether the noise level is potentially harmful, dangerous, or very dangerous.	Yes
Decibel (Sound) Meter	Hongwen Yang	✓		• F&M – Harmful level indicators: Coloured bar indicates whether the noise level is potentially damaging, dangerous, or very dangerous.	Yes
Sound Meter App - Frequency Meter	The Bright Apps	✓		• F&M – Harmful level indicators: Danger level shown on a dial.	Yes
Decibel Meter(Sound Meter) Pro	Dmytro Hrebeniuk	✓		• F&M – Harmful level indicators: Danger level shown on a dial.	Yes
Sound Meter	john marin	✓		• F&M – High noise level indicator: 70-100 dB = high, >100 dB = high-high.	Yes
SoundMeter X	Faber Acoustical, LLC	✓		• F&M – Dose: Percentage of daily noise exposure reached.	Yes
NoiSee	EA LAB	✓		• F&M – Dose: Percentage of daily noise exposure reached and time until 100% of dose is reached.	No
Decibel X - dB Soundmeter, SLM	SkyPaw Co. Ltd	✓		• F&M – Dose: Percentage of daily noise exposure reached and breakdown of exposure per noise level according to NIOSH or OSHA guidelines.	Yes

Decibel : dB sound level meter	Vlad Polyanskiy	✓	• F&M – Dose: Percentage of daily noise exposure reached and breakdown of exposure per noise level according to NIOSH or OSHA guidelines.	No
Decibel X PRO - dB Sound Meter	SkyPaw Co. Ltd	✓	• F&M – Dose: Percentage of daily noise exposure reached and breakdown of exposure per noise level according to NIOSH or OSHA guidelines.	Yes
Noise Dosimeter NIOSH & OSHA	Vlad Polyanskiy	✓	• F&M – Dose: Percentage of daily noise exposure reached and breakdown of exposure per noise level according to NIOSH or OSHA guidelines. Realtime alerts.	No
dB Meter & Spectrum Analyzer	Vlad Polyanskiy	✓	• F&M – Dose: Percentage of daily noise exposure reached and breakdown of exposure per noise level according to NIOSH or OSHA guidelines.	No
SoundLog Noise Dosimeter	Australian Hearing Services	✓	• F&M – Safe exposure time estimate.	Yes
Noise dosimeter	Srokowski Maciej	✓	• F&M – Noise level averaged over an 8 hour day and a 40 hour week (indicates it should not go over 85 dB).	No
Sound Meter : Decibel Meter, Noise Detector	The Card Shop	✓	• F&M – Noise exposure times: NIOSH standard.	Yes
Decibel Meter Pro	Performance Audio	✓	• F&M – Noise exposure times: Categorises safe exposure times as 90 dB for 2 hours, 95 dB for 1 hour, 100 dB for 15 mins, 105 dB for 5 mins, 110 dB for 2 mins, 115 dB for 30 seconds, 120 dB for 15 seconds, and anything above this as safe for 0 seconds.	No

SPLnFFT Noise Meter	Fabien Lefebvre	✓			• F&M – Noise exposure times: Lights up when exposure time should be < 2 h 30 mins, < 15 mins, and < 1 min, but does not specify the dB levels for these.	Yes
SoundPrint†	SoundPrint	✓			• F&M – Noise levels recorded in restaurants: Rates the restaurant as loud, moderate, or quiet.	Yes

Note: F&M = feedback and monitoring, NC = natural consequences, SK = shaping knowledge.
†Google Play version: subjective ratings only. Apple version: decibel measurements can be made.

The most comprehensive app of all those assessed here was the NIOSH Sound Level Meter which included the user's noise dose, the NIOSH recommendations, and information on what noises can cause hearing loss, how to prevent hearing loss, how to conduct a noise survey, how to select proper hearing protection devices, and how to insert earplugs. In addition to the time-weighted sound level (L_{Aeq}), it also showed the user's instantaneous noise level, and other parameters (L_{max}, L_{Cpeak}). It did not, however, include a breakdown of the user's noise dose by different sound levels, and the results were only displayed numerically – adding a colour-coded dial or bar graph could further enhance this app.

The other app that included three behaviour change techniques was SmarterNoise - video sound meter recorder camera. This app measures and records sound levels in video and audio format and has icons which help the user understand how hearing, cognitive performance, and health may be affected during different levels of noise exposure. This app however does not include the time-intensity trade-off which is vital to understanding safe noise exposure durations.

One interesting app from the search that was designed for a specific purpose was SoundPrint. Most of the other apps assessed were designed to measure sound levels anywhere, however, SoundPrint was designed for measuring the noise levels in venues such as restaurants, bars, and coffee shops, and used crowdsourcing of the data to develop a noise database. The Apple version of the app allows the user to measure and submit the noise level of a venue to the database. The Google Play version allows the user to subjectively rate the noise level of a venue and submit it to the database. Both versions allow the user to search for venues based on their noise level (i.e. quiet, moderate, or noisy).

Discussion

The aim of this study was to compile a list of noise apps that are currently available, assess their features, and determine whether they contain any behaviour change techniques to encourage the user to minimise their noise exposure. A total of 170 Apple store apps and 500 Google Play store apps were returned in the searches, and 250 of these met the criteria to be included in the study as sound level or noise meters. The majority of the apps displayed the result of the sound measurement in decibels. Other common displays were a dial, bar, graph, loudness descriptor, and/or loudness chart. The use of colour as visual feedback (which has been shown to significantly lower listening volumes compared to when there is no visual feedback on the sound level (Knox, 2009)) to indicate different noise levels was evident in 40% of apps.

Of the 250 apps coded, only 47 (19%) incorporated behaviour change techniques: with ‘feedback and monitoring’ appearing in 45/47 apps. ‘Natural consequences’ was found in 17 apps, whereas ‘shaping knowledge’ was found in only four apps. Two apps incorporated three behaviour change techniques, 15 apps incorporated two behaviour change techniques, and 30 apps incorporated one behaviour change technique. The extent of behaviour change techniques found in the noise apps is similar to the findings of Conroy et al. (2014) who found fewer than four behaviour change techniques in most of the physical activity apps they assessed. While this number may seem low, it is important to note that more behaviour change techniques does not necessarily mean a more effective app (Crane et al., 2015).

It was notable that there was only a limited range of behaviour change techniques were found in the noise apps. Other techniques from the Michie et al. (2013) taxonomy could also be beneficial to include in a noise app, such as ‘repetition and substitution’. This could be used to encourage habit formation such as wearing earplugs by alerting the user when they are exposed to a certain noise level to use earplugs. Through regular repetition, this behaviour could become automatic and improve the user’s hearing health. ‘Goals and planning’ is another technique which has been used in other health apps to prompt users to set a goal as a way of motivating behaviour change. In this case, users could be prompted to stay under the daily noise dose for a certain number of days in a row. Pre-commitment strategies can be used to help achieve certain goals. People are more likely to act in accordance with their goals if they pre-commit to engaging in the action (Sunstein, 2014). Motivation for the action can be further improved by committing to the action at a precise future point in time (Sunstein, 2014).

One of the most important considerations that underpins the damage-risk criteria for noise exposure (and one that is likely to be poorly understood by the general public), is that the degree of risk associated with any given noise level is dependent on the duration of the exposure. Ideally, this information would be included in an app through the ‘feedback and monitoring’, or ‘shaping knowledge’ technique, however, only 14 apps provided time-based information, and of these, only seven referenced the NIOSH or OSHA damage-risk criteria. One app had its own time-intensity trade-off which produced similar values to the NIOSH standards, however two apps suggested that serious hearing damage can occur if listening to 100 dB for 8 hours, which is at odds with both OSHA and NIOSH criteria which limit daily exposure to 100 dB to no more than 15 minutes and 2 hours, respectively. Additionally, many apps provided charts that showed hazardous sound levels, but did not specify the safe listening time at these levels.

Only four apps incorporated the ‘shaping knowledge’ behaviour change technique by including information about noise-induced hearing loss, and only one of these apps explained the time-intensity trade-off. This is surprising given this is a vital aspect of understanding noise exposure, but one that is not well understood (see Beach & Gilliver, 2015). It is possible that the developers assume that the users already know about this, but this should not be expected. Alternatively, it may be that the developers themselves are unaware of the time-intensity trade-off or do not think it is important to include. Two apps explained that noise-induced hearing loss can occur for sounds over 85 dB but did not specify the time, and the other app explained that noise can be dangerous and cause tinnitus, hearing loss, or hypersensitivity and that the louder the noise, the shorter the time needed to develop hearing loss, but again, it did not specify the noise levels and durations at which this occurs.

Eight apps activated an alarm when the noise reached a certain level. This could be a helpful feature, however the level at which the alarm sounds is determined by the user, so it is dependent on the user knowing what level is harmful. Furthermore, as the risk associated with noise exposure is time-dependent, it would be more useful for an alarm to be triggered when a certain proportion of a person's daily noise dose has been reached or exceeded. For example, a reminder to take action to reduce one's noise exposure or move to a quieter area could be triggered when the user's noise dose reaches, say, 50%. Seven apps showed the user's noise dose as a percentage of the maximum recommended noise exposure over a day, however it was not clear if any of these apps had an associated alarm or vibration feature that was activated when the noise dose reached or exceeded 100%.

In this study, 16 Apple apps (17%) were also compatible with the Apple watch. With the emergence of smart watches, there is potential for noise monitoring apps to become even more accessible. A watch may give a more accurate measurement of a user's sound exposure as users wear a watch for long periods of time, the microphone is likely to be uncovered most of the time, and the user can easily access vibration alerts from their watch. In contrast, a user's phone is often carried in a pocket or bag and the phone microphone may be covered or obscured resulting in an inaccurate sound level measurement. The recently released Apple Watch OS 6 and iOS 13 include new features that measure the sound levels in the environment and alert the user when the sound level reaches a level where hearing could be affected according to the WHO-ITU guidelines. Users can also track their noise level data over time within the Health app on the iPhone.

Limitations

This study has some limitations. Because new apps are added frequently to the app stores and apps are updated with additional features from time to time, additional or improved noise apps may have become available since our assessment was conducted. This study was not intended to be a comprehensive assessment of the quality of noise apps – its main focus was on behaviour change techniques, not the accuracy of the noise measurements, quality of design, ease of use, or reliability. Before choosing an app to download, users should consult other research (e.g. Kardous and Shaw (2014)) which focuses on measurement accuracy and reliability.

Future Directions

The results show that there are behaviour change techniques in almost one in five of the noise apps available on the Apple and Google Play store. However, it is unknown whether these behaviour change techniques are effective in prompting or sustaining a behaviour change; nor whether there is an optimal number of techniques which should be included in an app without it becoming too complex. Future research is needed to assess the efficacy of the different techniques in changing users' noise exposure behaviour and to determine whether there is a relationship between a user's existing engagement with hearing health and their use of noise apps. Some future research questions include:

- Whether a coloured dial or bar indicating the harmfulness of the current noise level promotes users to reduce their noise exposure;
- Whether a feature that shows the user's overall noise dose percentage and a breakdown of risk associated with different sound levels/durations following the NIOSH, OSHA, or WHO-ITU guidelines promotes users to change their noise exposure to stay within a specified the daily limit;
- Whether an alarm that alerts the user when the safe exposure level is about to be reached or exceeded and informs the user on what action to take (e.g. move to a quieter place or wear hearing protection) results in users actually undertaking these actions;
- Whether an information section on noise, noise-induced hearing loss, and hearing protection (including how to insert earplugs) results in users reducing their noise exposure.

Conclusions

This study assessed the noise apps available on the Apple and Google Play stores, coded their features, and analysed whether they contained any behaviour change techniques. The results revealed up to three behaviour change techniques in 19% of noise apps. Future research is needed to assess whether these behaviour change techniques are effective for changing users' noise exposure habits and to better understand the optimal combination of behaviour change techniques that is most likely to create sustained behaviour change and a long-term shift towards safer listening behaviours.

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