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INTRODUCTION

Since its inception in the 19th century, the London Underground has long been considered a great icon of British transport engineering, innovation, and technology. According to a Transport for London (TfL) feasibility report, a total of 1.25 billion customers used the London Underground between 2013 and 2014.1 TfL figures show that the average journey time for commuters across all lines was 47 minutes between 2014 and 2015.2 London’s population is expected to grow to an expected population of approximately 10 million by 2030.3 With this anticipated growth in the United Kingdom’s (UK) capital, expansion of the current underground system is naturally being considered in order to keep up with an increasing number of travelers using the service. The London Underground is the world’s oldest underground system, with the Piccadilly and Northern lines being opened in 1863.4 Bakerloo and Central lines are estimated to see an increase in passengers by 25%.3 The Piccadilly and Waterloo lines are anticipating an even greater expansion of up to 60%, according to TfL.3

The World Health Organisation (WHO) estimates 5% of the world population, 360 million people, suffer from disabling hearing loss.5 While congenital causes (eg, maternal rubella, birth asphyxia, ototoxic drugs in pregnancy) of hearing loss are significant around the world, the most substantial (and avoidable) risk factor of hearing loss is exposure to excessive noise.4 In an era of increased industrialization, with the use of heavy machinery and transport/traffic noise in addition to recreational noise from personal audio devices, sporting events, and concerts; noise induced hearing loss (NIHL) has become an increasing public health priority and a global burden of disease.5

In the United Kingdom, hearing loss affects around 45,000 children and 10 million adults, estimated to increase to 14.5 million by the year 2031.6 The cost of hearing loss as a whole costs the UK economy £25 billion a year in productivity and unemployment.6 Worryingly, it is believed that unemployment rates are 30% higher in those of working age suffering from a severe hearing loss compared to those with normal hearing thresholds.6 The National Health Service (NHS) is estimated to have spent £450 million managing hearing loss in the fiscal year of 2010/11.6 According to NHS England, 42% and 71% of the

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**Objectives:** There are no hearing protection regulations in place for passengers using public transport, such as the London Underground. In light of this, we sought to examine sound pressure levels experienced by regular users of the London Underground.

**Methods:** Sound pressure levels (A-weighted decibels: dBA) were taken on moving London Underground carriages between Euston and South Wimbledon on the Northern Line, and between Euston and Vauxhall on the Victoria Line, during 2006 and 2018. In addition, carriage sound pressure levels travelling within Zone 1 of the London Underground were tested in 2019. Three experimental and three technical repeats were undertaken using a hand-held calibrated multi-function sound level meter.

**Results:** Passengers are routinely and consistently subjected to sound pressure levels exceeding 80 dBA, with levels sometimes reaching over 100 dBA.

**Conclusion:** This study is unique within the literature, with no published studies outlining exposure levels for London Underground passengers. It provides evidence of elevated noise exposure to passengers, consistently along large stretches of the London Underground, over a prolonged study period (2006–2019).

**Key Words:** Sensorineural hearing loss; sound pressure; exposure; London underground; tube.

**Level of Evidence:** N/A

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population over the age of 50 and 70, respectively, suffer from hearing loss. With an increasingly ageing population and an ever-increasing noisy environment, these figures are set to rise.

At present, the implementation of the European Physical Agents (Noise) Directive as the Control of Noise at Work Regulations 2005 came into force in April 2006, covering all UK workers. This implemented an action level of 80 decibels (A weighting; dBA), with an upper value of 85 dBA. They also stipulate an absolute exposure limit value of 87 dBA, above which no worker can be exposed, without the mandatory use of hearing protection. Within the US, recommended exposure limits for workers are outlined by the National Institute for Occupational Safety and Health (NIOSH). These set a daily (8-hour) average limit of 85 dBA. If the noise experienced is higher, the recommended time of exposure decreases, so that at sound pressures of 94 dBA only 60 minutes daily exposure time is recommended. When pressures are over 100 dBA this drops to only 15 minutes. Although these are useful guides and an interesting comparison, unfortunately at present they do not cover non-occupational exposure, for which there is no legislation.

There are limited studies within the literature examining sound pressure exposure while using public transport. Of these, many revealed exposure levels above 80 dBA, but often reached over 100 dBA. Subway/Underground transport methods were normally associated with higher mean sound pressure levels, and therefore deemed to place individuals at higher theoretical risks of noise induced injury. In response to a number of reports in news outlets showing high noise exposure levels on the London underground system, with no published studies within the literature, we sought to formally examine sound exposure.
pressure exposure levels, which may be a significant contributing factor to noise induced hearing loss.

METHODS

Ethical Considerations

As no study participants were included ethical approval was not required.

Study Design

Permission was gained from the British Transport Police and London Underground Occupational Health department prior to beginning the study in 2006. When deemed necessary, an escort was available, to avoid alarming the public during monitoring sessions. Figure 1 displays external (A & B) and internal (C) London Underground carriage pictures.

Monitoring was undertaken in the fourth carriage from the front, with three experimental (three separate journey measurements on three separate days) and three technical (three sound pressure measurements per journey leg) repeats. A hand-held calibrated PeakTech 5035 (PeakTech RCE, Salerno, Italy) multifunction meter (Fig. 1D) was used to take sound pressure measurements in dBA from the middle position of tested carriages, within 2 m of the opening doors. A-weighted dB measurements were taken to the north of each station with the carriage moving in a southerly direction. Individual spot readings were taken and means calculated using Graphpad.

For the Northern Line, stations from Euston to South Wimbledon were studied. For the Victoria Line, stations from Euston to Vauxhall were studied. Measurements were taken initially in 2006, with the study repeated in 2018, with an additional Zone 1 survey undertaken in 2019. The number of passengers, including those wearing personal listening devices, were studied for each journey leg within the test carriage for the 2018 data collection period.
**Statistical Analysis**

Results were analyzed using Graphpad Prism Version 7 (GraphPad Software, San Diego, CA, USA). Unpaired t tests were used to measure significance levels (0.05) of dBA measures across the Northern and Victoria lines between 2006 and 2018. One-way ANOVA was used to compare results for the Zone 1 survey undertaken in 2019.

**RESULTS**

Figures 2 and 3 reveal that all mean sound pressure levels (dBA) taken along the Northern Line and Victoria lines in 2006 and 2018 were above 80 dBA. They also show a statistically significant difference between the reading from 2006 to 2018, P < .01 for the Northern Line, and P < .001 for the Victoria Line. This represented a mean drop of 4.9 dBA for the Northern line, from 97.4 dBA in 2006 to 92.5 dBA in 2018, and a mean drop of 7.7 dBA for the Victoria line, from 98.5 dBA in 2006 to 90.8 dBA in 2018. During the 2018 study period, there was a mean of 28.05 passengers per carriage, with an average of 5.1 passengers per carriage using personal listening devices.

Leicester square had the highest mean sound pressure level in 2006 for the Northern line at 97.9 dBA and South Wimbledon in 2018 at 96.8 dBA. For the Victoria line, Pimlico had the highest mean sound pressure level in 2006 at 101.0 dBA and Vauxhall in 2018 at 94.7 dBA.

Table I outlines the mean and standard deviation (SD) sound pressure levels taken along Zone 1 of the London Underground lines. All routes displayed mean sound pressure levels above 80 dBA. Paddington had the highest mean sound pressure level at 104.5 dBA, with the lowest measured at Monument at 75.1 dBA. There was a highly significant difference between the sound pressure levels (dBA) taken along the Northern Line and Victoria line, P < .001 for the Victoria Line. This represented a statistically significant difference between the reading from 2006 to 2018, P < .01 for the Northern Line, and P < .001 for the Victoria Line. The significant impact excess noise can have on wellbeing, and aims to try and limit unnecessary noise exposure within the city over the next decade.13 Within the workplace, “The Control of Noise at Work Regulations 2005” outlines that workers exposed to over 80 dB (daily average exposure) require hearing protection information and training, with those exposed to over 85 dB requiring employers to provide hearing protection and hearing protection zones. Indeed, the act also stipulates an average exposure limit, currently set at 87 dB, for which a worker should never be exposed without mandatory hearing protection.7 Within the US, recommended exposure limits for workers are outlined by the National Institute for Occupational Safety and Health (NIOSH),8 setting time exposure limits based on the length of noise exposure. Mean sound pressure levels in this study were consistently higher than 87 dBA, with some stations reaching over 100 dBA within 2006 and 2019. Although these legislation limits are stipulated to employees, these results suggest that commuters are potentially being exposed to harmful noise levels, depending upon how long their exposure periods are. NIOSH currently set daily exposure limits of 15 minutes to sound pressures over 100 dBA, which could be achieved if traveling on certain routes, as outlined in this study. However, these limits are set for occupational exposure, and therefore they are not directly comparable to non-occupational exposure, for which there currently is no legislation.

This study highlighted that approximately 18% of the passengers wore some form of headphones, either in-ear or on-ear. Use of such devices, in an already loud external environment, could potentially put further people at risk of hearing issues. Of note, these often need to be turned up, to drown out external noises, but may not be turned down again once external noise levels drop. Combining this with a recent survey suggesting that Londoners have an average commute time of 74 minutes, almost twice that of the worldwide average of 40 minutes,15 this could represent a significant increase in high volume noise exposure.

Study results highlight the variability in sound pressure exposure in different stations and stretches of the underground system. It is difficult to say exactly why these stretches were so different, but rail and station

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**DISCUSSION**

The London Underground remains a pivotal system of transport for commuters and the public in the UK’s capital. This novel study highlights potentially harmful levels of noise exposure to passengers during their journeys.

Whilst there is legislation in place protecting workers exposed to high levels of noise, there is no such protection or guidelines in place for the public and commuters. This is an obvious cause for concern in light of the increasing number of the population presenting with hearing loss. The City of London noise strategy highlights that the increasing number of the population presenting with hearing loss. The City of London noise strategy highlights the significant impact excess noise can have on wellbeing, and aims to try and limit unnecessary noise exposure within the city over the next decade.13 Within the workplace, “The Control of Noise at Work Regulations 2005” outlines that workers exposed to over 80 dB (daily average exposure) require hearing protection information and training, with those exposed to over 85 dB requiring employers to provide hearing protection and hearing protection zones. Indeed, the act also stipulates an average exposure limit, currently set at 87 dB, for which a worker should never be exposed without mandatory hearing protection.7 Within the US, recommended exposure limits for workers are outlined by the National Institute for Occupational Safety and Health (NIOSH),8 setting time exposure limits based on the length of noise exposure. Mean sound pressure levels in this study were consistently higher than 87 dBA, with some stations reaching over 100 dBA within 2006 and 2019. Although these legislation limits are stipulated to employees, these results suggest that commuters are potentially being exposed to harmful noise levels, depending upon how long their exposure periods are. NIOSH currently set daily exposure limits of 15 minutes to sound pressures over 100 dBA, which could be achieved if traveling on certain routes, as outlined in this study. However, these limits are set for occupational exposure, and therefore they are not directly comparable to non-occupational exposure, for which there currently is no legislation.

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curvature, acoustics and track defects may have had an effect. Also different stretches of the underground use different carriages which may also contribute to differing noise levels. Results highlighted a general reduction in sound pressure readings between 2006 and 2018. TfL have modified a large proportion of the fleet, and currently spend approximately £1,500,000 each year on track improvements, including a dedicated annual budget of £1,000,000 to develop rail noise technology. There are no legal limits on the amount of noise or vibration from trains operating on existing railways, but TfL say they are committed to minimizing disturbances in the future.

Interestingly, this study is rather unique within the literature, with no long-term published studies identified outlining exposure levels for London Underground passengers. There have been a number of articles published within the media, monitoring noise levels on the underground system. In similarity to this study, they have reportedly shown significant noise exposure levels, often up to and beyond 100 dB. This study provides unequivocal evidence of elevated sound pressure exposure to passengers, consistently along large stretches of the London Underground, over a prolonged study period.

CONCLUSION

In conclusion, this study has highlighted significant sound pressure exposure levels within London Underground carriages, which on average are consistently above 80 dBA, but also reach up to 100 dBA at some points. Although there has been a statistically significant reduction in sound pressure exposure from 2006 to 2018, sound pressure levels are still consistently elevated. We encourage travelers to be mindful of the risks to their hearing, and would implore Transport for London to explore ways of limiting noise exposure to those travelling through the underground network. These may include greater education for passengers into the risks and recommendation of noise protection with extended commutes, better train design to shield passengers from exposure, and technological advances to reduce track friction and defects.

AUTHOR CONTRIBUTIONS

TS created the study design and concept, collected the original data, and reviewed and revised all versions of the manuscript. TB analyzed all data, and wrote and revised the final manuscript. EC, MF, AM, AS, TP, NJ, and AD collected the data in 2018 and 2019, as well as reviewing and revising the final manuscript. FS and KM were involved in the original design of the study, helped collect the 2008 data, and revised the final manuscript. HS and PB oversaw the completion of the project, reviewed data analysis, and critically reviewed and revised the final manuscript. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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