Common failings of inter-disciplinary studies on noise and the potential solutions

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Abstract

Inter-disciplinary research has been published on the adverse effects of noise in health, education and other areas. These studies often produce findings that on close examination are ambiguous; display flawed methodology and conclusions not supported by the measurements. This paper highlights common anomalies and errors in noise assessment which have passed through the peer-review process to publication in journals. Often ambiguity in the findings is the result of using incorrect notation and terminology, combined with a poor understanding of appropriate noise descriptors. It is common practice to perform the statistical analysis on the sound levels in decibels. But this leads to an underestimation of the effect because adverse health effects of noise typically display a dose response to the product of the sound pressure squared and time. Methodologies are often described without reference to best practice or existing standards that typically describe in detail robust measurement procedures. There is a need to educate researchers involved in noise studies about the need for competency in noise measurement and assessment. It also highlights to journal editorial staff about the need to include in their peer review process someone with appropriate expertise in noise.

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1. Introduction

Noise is ubiquitous and pervasive in most aspects of modern society. As the adverse effects of excessive noise on human health and learning in education environments become more widely known, it is evident that issues of noise will cross many other disciplines and situations. These include the effects of noise on learning and educational performance, particularly for individuals experiencing disabilities such as autistic spectrum disorders (ASD) and hearing impairment. It also includes the effects of noise producing consumer products such as toys, fireworks and power tools.

In the case of educational facilities for children, hearing and auditory specialists have indicated that acoustics must be considered in the design of the learning environment and have called for noise experts and those delivering education to work together to improve the learning environment [1-3]. As a result, there has been an increase in the number of studies on noise in educational environments in reputable peer-reviewed journals. Some of these articles contain fundamental errors, including: incorrect use of equipment and calibration procedures; incorrect notation leading to confusion in interpretation; flawed study design; and use of assumptions and data processing which have questionable validity.

This paper will critically examine a number of articles from peer-reviewed journals where serious errors are evident and also investigate how the noise and acoustics discipline can address the flawed review process which allows such errors to pass undetected. Such articles are generally not published in specialist acoustic journals such as the Noise Control Engineering Journal, Acoustica, Noise and Health or the Journal of the Acoustical Society of America. If they were, competent reviewers in the discipline would recognize such deficiencies as part of the review process and they would be addressed before publication. It is clear in cases where fundamental errors are present that those who reviewed the article had little knowledge of the scientific concepts of sound and acoustics and have therefore taken this component of the paper as being accurate. There appears to be a belief among some researchers that they can conduct a complex noise study with little or no knowledge of the science involved. It also appears that these researchers have little appreciation of the procedures and established standards in the use of sound level measurement equipment and believe they can acquire such instrumentation and operate it competently with the minimum of instruction. Furthermore, some authors have demonstrated a fundamental lack of understanding of the decibel scale when applying statistical calculations and interpretation of data.

2. Case Studies

2.1 Noise in education – Case 1

A study by Maxwell and Evans [4] in 2000 examined the links between chronic noise exposure and reading skills in early childhood education. Ninety children aged 4-5 years were tested on cognitive measures of pre-reading skills in a learning space with poor acoustical quality. Sound level measurements were taken to establish a measure of the acoustical quality of the learning space. In the following year, some acoustical treatment of the learning space was applied and then the tests of both sound levels and testing of the children's pre-reading skills were repeated. The study reported that the cohort in the quieter environment performed better than those tested before the acoustic treatment of the space was carried out.

The first indication that should have raised questions with the reviewers came from the use of the term *decibel meter* and *decibel level*. The correct or formal terminology should be *sound level meter* and *sound pressure levels* measured in decibels.

The study refers to time-average levels ($L_{Aeq\,t}$) using the notation *Leg* throughout the document. Acoustical quality of the learning space was assessed by measuring the sound pressure levels generated in the early childhood center during a specified time. The noise descriptors were described as "*Average decibel level and Peak decibel level*". We interpreted these to be the arithmetic average of the $L_{Aeq\,t}$ readings in decibels for each session. The peak decibel values do not appear to be true peak levels although the instrument used in the study (a B&K 2236) is able to measure peak levels using C or linear frequency weighting (now replaced with Z weighting on modern meters).

The study states that "*Peak and average Leg noise readings were obtained by placing a decibel meter (B& K model #2236) in each classroom for 4 hours duration during similar classroom activity periods*". From this and the use of the term *Leg*, we assume the measurements were the time-average level, $L_{Aeq,4h}$. Consulting the user manual for the sound level meter, *Leg* is probably a mistyped version of *Leq*, the continuous equivalent sound level now known as the time-average level, L_{Aeq}.

While no frequency-weightings were explicitly stated by the authors, they quoted Kryter (1985) [5] stating "*that steady noise at 45 dBA or peak noise (aircraft, cars etc.) at 55 dB A will interfere with speech communication*". Kryter did quote peak levels as A-frequency weighted but in the mid-1980s, instruments capable of measurement of true peak levels were very scarce and what was quoted then were probably the A-frequency weighted, F-time weighted maximum sound pressure levels (L_{AFmax}). However, by the time of the reported study was undertaken, sound level meters such as the one used by the authors could measure peak levels, which are very different from the A-frequency weighted peak values referred to by Kryter, some 15 years earlier. One contributing factor as outlined by Narang and Bell [6] explained that the old IEC 56061 standard for specifications of sound level meters made no reference to the frequency weighting so that such measurements were often done using A or linear frequency weightings rather than the C weighting today.

2.1.1 Confounding factors

The readers would be entitled to question how differences in classroom activities and other confounding factors in the testing regimes before and after treatment were accounted for. Children are not machines and therefore are not going to make exactly the same level of noise from one day to the next. To give an example, in childcare centers which have outdoor play areas, such factors as seasonal weather conditions which may confine children indoors will probably result in very different sound levels to those times when children can go to outdoor play areas. Rates of absenteeism due to sickness are expected to vary greatly throughout the year, affecting the number of children present. Such issues are major confounding factors which will contribute to overall noise levels.

2.1.2 Attenuation with acoustic treatment

There was little explanation in the article of the acoustic treatment applied. It was stated that "semi-height partitions were raised to full height to prevent noise intrusion from other rooms" and that acoustic panels where hung from the ceiling trusses. All certified acoustic treatment materials such as composition panels, ceiling tiles and so forth have an acoustic rating known as a noise reduction coefficient (NRC). Such information would have been useful to any reader contemplating similar acoustic treatment for their facilities.

2.1.3 Appropriate determination of acoustical quality

It is unclear as to why the authors of this study chose peak levels as a measure of acoustical quality. They rightly stated in the text that an appropriate measure of acoustical quality was reverberation time. Commonly, reverberation time is the primary measure for the evaluation of acoustical quality of a room (RT60) [7]. It was not used in this study, presumably because the equipment was not available to make the measurements. While it is well known that reverberation time only gives limited indication of room suitability for speech intelligibility [8], Bradley et al. [9] emphasize the importance of avoiding excessive reverberant sound. These authors found that the reflection pattern is very important in determining the level of speech intelligibility, rather than the measured reverberation level.

2.1.4 Application of statistics to logarithmic values

There were questions about the statistical calculations performed. The decibel scale is a logarithmic scale and has the effects of greatly condensing the sound pressure level range when compared to the original linear units of pressure expressed in Pascal-squared (Pa^2). The human dose response to sound energy received is typically a linear relationship [7] so a doubling of the sound pressure level increases the dB value by only 3 dB. If levels are expressed in dB units, it is essential from a dose perspective that the dB values are converted back to their linear equivalents before performing statistical analysis.

2.2 Noise in education – Case 2

A similar recent research article by Kishimoto in 2012 [10] involved the acoustic treatment of an early childhood center learning space in Brazil. The author is from a College of Education and an acoustic laboratory service was engaged to make the sound measurements. However, there appears to be little acoustic technical input into the interpretation of the sound level data. The author describes "audiometers" as the equipment used (to measure noise levels) to achieve a first evaluation of the situation which also involved measurement of sound levels after applying acoustic insulation to the space. There is clear confusion as to the difference between an audiometer used for hearing evaluation and a sound level meter for measurement of sound pressure levels.

The Brazilian Technical standards for noise were quoted and yet these lacked basic components. A sound pressure level of 40-50 dB A (40-50 dB LpA) was given. However it was not explicit if this was an unoccupied (background sound pressure level) criteria or during education activities where the children and their teachers were present. From experience, this was likely to be an unoccupied background level as if the children were present, they would have had to be very quiet. The values should have been expressed in $L_{Aeq,t}$ dB with a specified time interval. A sound pressure level was given in the Brazilian Labour Standards Regulation "*of up to 65 dB (A), as the limit for comfort*". Finally, a Brazilian Labour Regulation was quoted "*as the limit above 85 dB (A) presents risk of hearing impairment*". This is likely to be the adoption of the international workplace criteria of an A-frequency weighted time-average level of no more than 85 dB over an 8 hour working day ($L_{Aeq\ 8h}$ < 85 dB). This workplace criterion may apply to teaching staff as workers, but it is not applicable to children. In the absence of specific criteria for children, it is common practice to take an existing standard and make some adjustments for children but the limitations of undertaking this practice need to be stated. A similar statement was made in Coppla, Enns and Grandin [11] , "*this exceeds OSHA regulation for workers (90 dB A)*".

This study attempted to use noise measurements in the learning space as a measure of improved acoustic quality. This is problematic due the many confounding factors which must be taken into account. The sound descriptors used were not defined. It would appear from the article that 10-minute time-average levels ($L_{Aeq\ 10min}$ dB) were used but this is not explicitly stated. Five rooms were evaluated by taking sound level measurements in each. An A-frequency weighted time-average level over a full session of an hour or more of 82 dB would be of concern, but this would not be the case for an isolated event producing a maximum sound pressure level (L_{AFmax} dB) of this value. The highest noise level quoted was in room 3 at "*92 dB A*" in the morning session. Four years later in 2011, some type of acoustic treatment in the form of "*anti-noise gypsum plaster modules*" were acquired and were fitted to the ceiling. If these were certified noise insulation materials, then an NRC value should have been quoted to indicate the effectiveness of the material and also allow readers who might be considering a similar treatment to source equivalent performing materials.

The author stated "*The 2011 data (after treatment was carried out) showed a significant decrease in dB (A), compared to the ones in 2007 before treatment was carried out. Most values are between 54 and 58 dB (A) with a reduction of the maximum distance between minimum and maximum indexes of up to 6 points (60-66 dB[A]) when compared to values obtained in 2007, which reached a 32 point difference (60-92 dB[A])*". This of course assumes that the same groups of children in 2007 and 2011 made exactly the same level of noise over the testing regimes and that any noise reduction was due to the attenuation of the learning space.

The results as presented were confusing when comparing the two sets of data from different years. For example data recorded before acoustic treatment in the mornings of Room 1 is shown as a noise level of 60-70 dB (13 June 2007) and 63-75 dB A (18 June 2007) whereas the data recorded after treatment in the morning sessions of Room 1 shown as noise readings of 57/59 dB A (09 March 2011) and 58/62 dB A (15 March 2011). One has to presume that the second data set expressed a range of 57-59 dB A as indicated in the first data set.

2.2.1 Confounding factors

There is a major time difference of 4 years between the two sets of measurements and it is necessary to ask how the obvious confounding factors were addressed. The two sets of measurements were done in different seasons (June and March) which could be a significant confounding factor. If outdoor plays areas are provided, weather may have a major part in confining children indoors due to harsh weather conditions. If sound pressures levels are being measured inside while a number of children are outside playing, this will obviously have an effect on measured sound pressure levels. If education delivery is highly structured (this varies from country to country), observations and activity logs would need to be done with sound level measurements to describe exactly what was happening in the learning spaces and what was generating the noise. There was no reporting of this being done and no information provided about how such obviously confounding factors were addressed. Non-observed sound level measurements are of limited value for this reason.

As for the previous case, reverberation time (RT60) should have been the primary measure of acoustic quality and any sound level measurements should only be used as additional supporting information.

2.3 Peak levels and Maximum sound pressure levels

A common point of confusion often occurs between peak levels (using C or Z-frequency weighting) and A-frequency weighted maximum sound pressure levels (L_{AFmax}). A number of papers quote peak levels as "*A-weighted*" which in a modern context is clearly incorrect. A study by Yarechuk et al. [12] in 1998 in which a range of toys were screened using an instantaneous analogue sound level meter, followed by detailed measurements using a Larsen-Davis sound level meter model 800B, measuring L_{Aeq} dB and peak levels. In trying to determine what the actual descriptors used were, we obtained the manual for the Larsen and Davis 800B sound level meter to ascertain whether or not the meter was capable of measuring an un-weighted (linear) peak level and if so, if there was a lock-out on the meter to prevent the incorrect weighting being applied. The meter was capable of measuring both un-weighted (linear) or C-frequency weighted peak level but there was no lock-out mechanism to stop a user from choosing A-frequency weighting for peak level measurement. As an A-frequency weighted peak level was reported, one has to assume that this was what was actually measured even if it was an incorrect choice. Other publications where similar confusion between peak levels and maximum sound pressure levels include Coppla, Enns and Grandin [11] where peak levels were quoted as A-frequency weighted.

2.4 Notation

Unlike other well established disciplines such as chemistry where the same notation is universally accepted and used, a range of notation styles exist in the noise and acoustics disciplines. Notation can even vary between different international standards such as the ISO (International Organization for Standardization) standard for the safety of toys [13], the ISO standard for the determination of occupational noise [14] and the ISO standard for the determination of environmental noise [15][16]. The A-weighted time-average level (formerly the equivalent continuous sound pressure level) descriptor in the above standards on the safety of toys and determination of occupational noise exposure, use the notation $L_{pAeq\ T}$, with the use of a subscript 'p' to indicate that the level is pressure. There is even considerable variation and inconsistencies between different parts of the same standard as exists between Parts 1 and 2 of the ISO standard on determination of environmental noise levels [15][16]. Peak sound pressure levels are defined without any explicit frequency weighting in Part 1. Similarly frequency weighting for the Sound Exposure (L_E) is not stated, whereas it is most likely A-frequency weighted, while A-frequency weighting is explicitly stated for the continuous equivalent sound exposure level ($L_{Aeq\ T}$).

However, in Part 2 the notation is generalized to $L_{eq\ T}$ where the frequency weighing can be A or C weighting or that of a defined bandwidth. If different frequency weightings are permitted this should be explicitly included in the definitions perhaps with the notation $L_{Xeq\ T}$ where permitted X-frequency weighting are defined. In addition, the above environmental noise standard uses the notation $L_{eq,T}$ omitting the 'p'. There are a variety of other notation styles in common use such as $L_{Aeq,\ (t)}$ dB in the New Zealand Standard for the measurement of environmental noise [17] and the style L_{AeqT} dB in the Australian and New Zealand standard on occupational noise management [18]. The traditional style (now considered obsolete in many jurisdictions) of 'Leq dB A' where the time interval it not included, is still widely used. Apart from standard prefixes, the International System of Units (SI) rules do not allow the addition of suffix or prefix qualifiers to units such as the decibel [19]. While this has been common practice in acoustics and engineering disciplines for many years before the adoption of SI units, the use of notations such as dBA, dBC, dBu or dBm, is not permitted under SI protocols. Such variations can only be confusing to the readers who are not specialists in the domain of application. Ideally it should be mandatory that an international body such as ISO, uses a consistent nomenclature throughout all of its standards.

3. Discussion

It is the experience of the authors that in some cases reviewers and journal editors who are not experienced in noise measurement and so do not understand the technical nature of the subject, demand simplified text to ensure it better fits with their readership. In such situations significant care has to be taken in simplifying the language and notation to ensure it complete and not misleading. Ideally the core technical information should be included for those readers requiring it but done in such a way to not put off the general readership that might be from another discipline such as education. This can be most effectively achieved using a side-panel (containing a glossary of terms and definitions), so not to disturb the flow of the main text.

In the articles reviewed in this paper, confusion often exists between peak sound pressure levels (typically using C-frequency weighting) and maximum sound pressure which use A-frequency weighting. Articles by Maxell and Evans [4], Yaremuchuk et al [12] and Coppla, Enns and Grandin [11] all referred to peak levels as A-frequency weighted. Despite the dates when some of these articles were written, such errors should not have been made given that the instrumentation used in these studies was capable of measuring peak levels correctly. In legal articles, care must be taken over use of terminology in the general sense where there are specific legal definitions which will always take precedence. Authors of articles in sound and acoustics must take care when using such terms as maximum and peak when describing results in a general sense as this can lead to confusion. An example occurs in the paper by Kishimoto [10] which refers to "*peaks of noise*". This can create confusion between the genuine peak sound level descriptor and a local maxima in a time history graph of a particualr descriptor.

Another common issue is the statistical analysis of results expressed in decibel units when the underlying dose-response is a linear relationship between the product of the square of the sound pressure (Pascal-squared) and time. Since decibel units greatly condense the dynamic range, applying statistical analyses to dB values will greatly underestimates the true variance of the dose.

Often decibel values are shown to two-decimal places for results based on taking the arithmetic average of a number of readings. This level of apparent precision is simply not achievable even for a class 1 sound level meter. The New Zealand Standard for the measurement of environmental sound (17) requires in accordance with accepted best practice that decibel values used in calculations are performed to the resolution of the instrument (one decimal place) and all final values are rounded to the nearest whole number for reporting. There is a common "*rule-of-thumb*" guide for ligation purposes which is known as the '3-5-7 rule'. Any sound pressure level measurements taken for compliance purposes which are up to 3 dB in excess of a prescribed legal noise rule or standard are deemed to be compliant because they are within the margin of error. If an activity or operation generates noise which exceeds by up to 5 dB the prescribed legal level, then a formal notification as to the transgression can be made. However, legal proceedings or resolution by a judicial process should not be taken unless the breach is 7 dB or greater due to the level of uncertainly and the robustness of evidence required by the courts.

In the Australian and New Zealand standard for occupational noise measurement [18] the instrument is to be field calibrated with a reference sound source immediately before and after a sequence of measurements are made and if the prescribed variation is exceeded then all measurements taken in between the successive calibration are to be considered invalid. This is standard practice when using sound level meters but in this case the prescribed discrepancy is only +/-0.5 dB, which is unrealistic and probably beyond the manufacturer's specification. In the New Zealand environmental noise standards [17] a discrepancy of 1 dB is prescribed which is considerably more realistic. The occupational noise standard also requires that "*where such a level of discrepancy is recorded, the tester shall ascertain the reasons for minor variations*", which is clearly unreasonable. Environmental noise measurements are usually made over short durations (15-30 minutes) at different times of the day, whereas

personal sound exposure measurements are usually continuous and extend over a working day (8-12 or more hours) where many more confounding factors can come into play.

An article submitted to an acoustics journal concerning the findings of the acoustic treatment of a childcare center learning space are likely to be readily reviewed and technical issues identified by the reviewers. However if the same article is submitted to an educational journal where the focus is say on the improvement in learning outcomes of the children, this level of technical oversight may not occur. Thus it is essential in such a case that professionals with noise experience are engaged by the authors in the write up of the findings and not just in performing the measurements. Noise and acoustics should never be considered an exclusive science or discipline that belongs to a few as the often profound health effects from noise can be harmful and debilitating. It is critical to strive towards the sharing of expertise and dissemination of information in a manner which is meaningful without compromising the integrity of the data by oversimplification.

A review paper by Basner et al. [20] in the Lancet, is an excellent example of how to present and disseminate up-to-date information on noise to those who are not experts in the field. Embedded in the paper were a series of panels explaining the terminology and key noise descriptors such as sound pressure level, the logarithmic decibel scale and the WHO criteria for night noise levels. The authors have used current modern notation and have provided explanations where confusion may occur. This paper alone demonstrates that it is possible to write a high quality robust report and effectively disseminate information to those who may not be specialists in the science of noise and acoustics.

Finally, notation is highly varied and often leads to confusion and ambiguity. Different ISO standards use varying notation which is clearly not defensible in this age of international harmonization of standards. As a start, international bodies such as ISO should ensure consistent notation among all their standards and documents. There is now a need for the development and promulgation of a universal standard for noise and sound descriptors terminology. This notation should then be strictly applied and used by all.

4. Conclusions

The health effects of noise have now become a major issue of concern and due to the serious implications of the adverse health and wellbeing effects of noise, it is imperative that all studies involving noise and health effects are carried out in a scientific and robust manner. Serious errors in taking measurements, processing of data and reporting of findings can negate the value of such studies and important findings which could affect the populations may not be reported. It is also necessary to ensure that such noise studies are reported in a way to enable easy dissemination of the information and findings to a wide range of readers and not just those with expertise in the acoustics discipline.

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