A new methodology to study the children's exposure to aircraft noise at school

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Summary

Many literary studies show a link between chronic exposure to noise and annoyance, problems with memory, attention and text comprehension. Some research demonstrate that children exposed for a long time to aircraft noise at schools show higher levels of stress, in addition to worst performance in mathematics, reading and text comprehension and to a minor attention span. Moreover, in some projects developed around Europe cognitive tests have been submitted to children with the aim of understanding if aircraft noise could influence their episodic memory, sustained attention, working memory, perceived noise and annoyance, etc.

In the current article, a new methodology to evaluate the real time aircraft noise perception of children, possible difficulties in text listening in presence of aircraft noise and the development of exposure-response curves is presented. The methodology consists in the following steps: characterization of real noise levels due to aircraft passages inside the classrooms; acoustic measurements of the façade sound insulation and of the reverberation times inside the classrooms; design of an electroacoustic system able to reproduce the aircraft events at the desired time; test of the system in presence of children concurrently with a text reading and submission of three questionnaires.

This Article is structured as follows. In Section 1 an overview of the main literature studies on the specific influence of aircraft noise on children is made and the main research challenges in this field are reported. Section 2 describes the main methods adopted and tested by some important European research projects for the purpose of administering cognitive tests to children exposed to aircraft noise. Section 3 illustrates each phase of the methodology introduced by the Department of Industrial Engineering of the University of Florence and the criteria for its application.

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1. Introduction

Many studies [1-5] show a link between chronic noise exposure and annoyance (common sense of stress or dissatisfaction in people when exposed to noise sources), memory problems, attention and understanding of the text.

In addition, several studies demonstrate the existence of an association between noise and learning disorders in children. Attention, memory and reading skills are all involved in developing the cognitive skills of children of primary school age (5-11 years). Children acquire information that is then codified in memory through a process of repetition, organization and processing (Kryster K., 1985) and strategies for retrieving information from memory are gradually developing. Reading ability depends on both perception and memory and, in the early stages, on the ability to recognize the sounds that make up a speech (Bryant P, 1985). Important

environmental factors, such as noise, can strongly interfere with the extent to which information is treated, maintained and recalled (Cohen S, 1986). Children are potentially more vulnerable than adults to the effects of noise because of their potential to interfere with learning at a critical stage of a person's development and their reduced ability to anticipate, understand and live with stressful elements such as noise. In [6] it is highlighted how children are less able than adults to use already memorized phonological knowledge and contextual clues to reconstruct a speech disturbed by external noise.

Recent works (van Kempen E, 2012, Clark C, 2012) document the association between environmental and aircraft noise and effects on children's cognitive level, also taking into account the effect of air pollution.

The effect of exposure to noise, aircraft and traffic noise on reading ability in primary school children is documented in literature (Matheson MP 2003, Stansfeld SA, 2003, Haines MM, 2001; Haines MM, 2002 Shield BM, 2008; Stansfeld SA, 2005) as well as a dose-response effect in the relationship between aircraft noise and reading ability is highlighted (Clark C, 2006). Specifically, several authors demonstrate the link between chronic exposure to road and aircraft noise and understanding of the text in primary school pupils [7-12]. In [7], chronic exposure to aircraft noise is associated with a six-month delay in reading literacy in children aged between eight and ten. Numerous epidemiological studies have been conducted on children living near major international airports (Los Angeles, Munich, London, etc.), with the aim of studying the relationship between aircraft noise and the academic performance of exposed children. The most important conclusions derive from the RANCH study (Clark C, 2006) which has the following results:

- aircraft noise is associated with decreased performance in reading comprehension and recognition memory;
- exposure to noise generated by vehicle traffic is unexpectedly associated with an improved performance in terms of recall memory, but not associated with reading comprehension, the ability to recall the stored information or operational memory;
- exposure to noise, from aircraft or road traffic, is associated with annoyance.

In [13], which takes up the results of the European project RANCH, the existence of a linear and decreasing link between exposure to aircraft noise and the ability to understand the text is demonstrated, following experiments conducted at Amsterdam, Madrid and London airports.

In some specific studies, an effort is made to trace the environmental and social factors that have the greatest impact on children's exposure to aircraft noise. In this regard, a correlation is highlighted between exposure to aircraft noise in the domestic and school environment, while it is reported that exposure to road traffic in the school environment does not have significant effects on the understanding of the text. The best reading performance is achieved in children whose mothers have a high level of education and in other well-defined circumstances. The objective of [14] is to study the relationship between annoyance and aircraft and road traffic noise in children and to compare these results with those obtained for adults. First of all, a series of analyses of the social data collected with the questionnaires show:

- a correlation between the level of education of mothers and the educational performance of children with aircraft noise;
- that in the domestic environment girls are less disturbed than boys by aircraft noise;
- that children are less sensitive to aircraft noise than adults above 55 dB at home, but much more sensitive than adults below 45 dB.

Also from this work, annoyance appears to be much more related to aircraft noise than road traffic noise, both in children and adults.

The different perception of aircraft and road traffic noise is due to the following reasons: aircraft noise is more intense and less predictive than road traffic noise; the nature of the first type of noise tends to distract children more easily and disturb their attention, while it is easier for children to get used to road noise, which is often a naturally constant sound.

In [5] aircraft noise exposure is linearly associated with a compromise in recognition, text understanding and recognition memory. However, neither air nor road traffic noise affect the ability to maintain a constant focus, mental health and self-referred health.

In [15], a comparison of the results obtained in relation to an area subject to closure of the present airport and an area subject to the opening of a new airport states that all cognitive processes requiring processing by the central language are particularly

sensitive to noise, even if there is a possibility that these processes are reversible. In addition, there is an improvement in running memory following the closure of the airport in the first zone.
In [16] the main results of the work of Haines et Al. are illustrated, reporting that children exposed to aircraft noise in school for a long time show higher levels of stress and that children exposed to chronic levels of aircraft noise also show worse performance in mathematics, reading and understanding of text and less attention.
In some more recent studies [17-19], children's resilience is proved to be higher than expected, i.e. that the capabilities of children accustomed to aircraft noise exposure are not affected by this noise source. In [20], referring to the DIA study and the RANCH project, it is concluded that in noisy environments children can develop resilience mechanisms for episodic and working memory, while in quieter environments they show much better performance with regard to perspective memory.
In terms of research challenges, in [16] the following are reported, among others:
- the need to improve the accuracy of exposure-response curves and update them by conducting further studies, since the annoyance due to aircraft noise has grown in recent years;
- the need to assess specific exposure-response curves for children;
- the need to study the long-term consequences of exposure to aircraft noise of children during school hours.

2. Methodologies already developed around Europe

Section 2 contains the most recent and structured tests aimed at assessing the influence of aircraft noise on certain cognitive aspects of children and used in major research projects at European level.
All the presented approaches are characterized by the fact that cognitive tests are made during the ordinary course of lessons, so not necessarily concurrently with real aircraft transits.

2.1. RANCH Project

The RANCH project [21], is the largest cross-sectional study of noise and children's health, examining 9-10-year-old children living around three major airports: Schiphol (Amsterdam), Barajas (Madrid) and London Heathrow (United Kingdom). Cognitive outcomes include reading comprehension, episodic memory, working memory, prospective memory and sustained attention. Health outcomes include noise annoyance, blood pressure, overall mental health and self-reported health. Confounding factors are adjusted for at the school and individual level, across three European countries.
Reading comprehension is measured by nationally standardized normed tests (Suffolk Reading Scale, CITO readability index for elementary and special education and the ECL-2). Episodic memory (recognition and recall) is evaluated by a task adapted from the child memory scale; sustained attention is measured by adapting the Toulouse-Pieron test for classroom use while working memory is measured by a modified version of the search and memory task. A questionnaire structured for children includes questions on perceived health, noise and annoyance based on standard adult questions. A questionnaire has also been sent home for parents to analyze also the parental version of the Strengths and Difficulties questionnaire and noise annoyance. A wide variety of potential confounding sociodemographic factors are also measured.

2.2. S.Am.Ba Project

The objective of the S.Am.Ba study (Study on the effects of the environment on the health of children living in Ciampino and Marino) [22] is to investigate the effects of exposure to noise on the health of children attending the IV and V classes of the primary schools located in the municipalities of Ciampino and Marino (Lazio, Italy), exposed to aircraft noise due to the proximity of the G.B. Pastine airport. In particular, the hypothesis of association between exposure to environmental noise and cognitive performance of children, perceived annoyance and blood pressure level is evaluated. Regarding the assessment of cognitive performance, children are given cognitive tests in class similar to those used in the RANCH project. Specifically, with regard to the text comprehension, the children are made to read a story in their minds and then answered 14 questions regarding the text they have just read; with regard to the episodic memory, the deferred memory and the associative re-enactment, children are made to listen to a story and, after 20-25 minutes, answer ten questions regarding what they had listened to using only the memory; while with regard to annoyance, the children are asked, through a questionnaire, to

express their level of annoyance due to aircraft noise.

2.3. NORAH Noise Impact Study

The NORAH Noise Impact Study [23] examines the chronic effects of aircraft noise on primary school children in 29 schools near the Frankfurt airport. The study, started in 2012, is concerned with the effects on the intellectual development of the children and it concentrates on reading acquisition and on certain language skills that are important for learning to read. The study does not focus on how loud it is in the classroom when children are learning, but on the possibility that continuous aircraft noise could influence the intellectual development of the children, demonstrating that they learn to read more slowly than children growing up in a quieter environment. NORAH has acquired noise levels describing the exposure of the children at home and in the school over a prolonged time period. Some of the tests scheduled in the NORAH project are carried out with headphones in order to eliminate as far as possible factors that hinder comprehension, such as acute aviation noise, noise from adjacent rooms, reverberation time in the classrooms, or the distance of the child from the teacher's desk. One of the tests concerns long-term memory and consists in reading a story to children who then are asked to answer questions on it, considering that earlier studies on the impact of aviation noise on the long-term memory had given rise to contradictory findings.

3. Methodology developed by the University of Florence

Concerning the addressed thematic, the Department of Industrial Engineering of Florence (DIEF) aims at introducing an alternative approach and methodology having as main scopes to understand if aircraft passages could influence the listening ability of children at school and the development of dose-response curves specific for children disturbed by aircraft noise.
To achieve this aim, the first problems to be addressed in the method development concern the difficulties to synchronize the test of listening ability with real time aircraft passages and the constraint due to the classroom's acoustic characteristics in terms of reverberation time and façade sound insulation.

To solve these problems, the main innovative elements of the proposed method concern:

- the design of an electro-acoustic system and an on-site listening laboratory to be considered equivalent to a classroom located near the take-off/landing paths of the airport;

- the processing of audio signals capable of reproducing the take-off movement of the airplane in open and closed window conditions, also representing different environmental configurations or windows with a different sound insulation, concurrently with the questionnaires submission;

- the possibility to reproduce the aircraft passage event in specific moments during the reading test.

The developed methodology consists in the phases illustrated in Figure 1. In this article it has been decided to give a general description of the individual phases of the method. The specific details will be given in future publications.

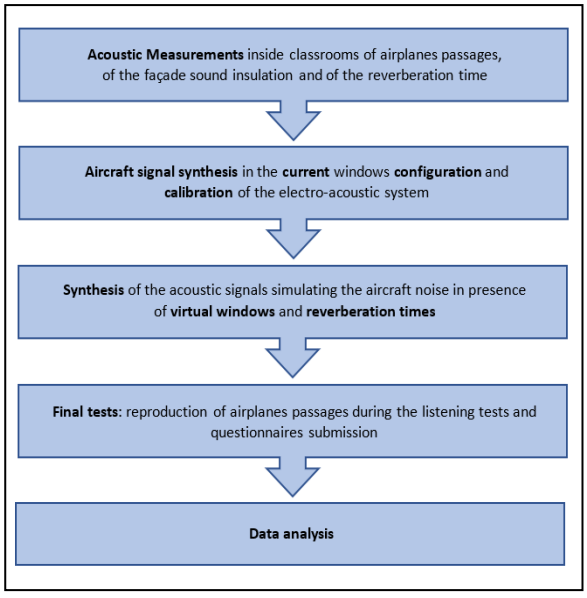

Figure 1. Main phases of the proposed methodology.

3.1. Acoustic measurements and characteristics of the electro-acoustic system

In the first phase of the method, the noise produced in a classroom by take-off and landing movements due to different types of aircraft is measured. For this first measurement, a wave signal is acquired in the open and closed window configurations. The measurement is carried out with a class I microphone and a measurement chain at one or

more microphone positions. The microphone is positioned at the student's ear in a sitting position, approximately 1.20 m from the ground.
Once all measurements have been carried out, the most representative signals for both open and closed windows configurations are selected.
In addition, standard measurements of the façade sound insulation and of the reverberation time in the room are carried out according to international standards [24, 25].
One of the main goal of the current research activity is to design an audio reproduction system able to play back a signal as close as possible to the measured one, by considering the effects due to the loudspeaker and the environment response. As for the definition and positioning of the audio reproduction system, a 5+1 reproduction system is used, with the trick of placing the mid-high frequency speakers so that they are directed towards the window from which the sound actually comes from the outside (Figure 2).

Figure 2. Positioning of the electro-acoustic system and of the measurement microphone in a classroom.

The window, which is closed during the tests (see sub-section 3.4), helps to spread the sound of the speakers to the interior and give the impression that the sound comes from the window itself.

3.2. Aircraft signal synthesis in the current windows configuration and calibration of the electro-acoustic system

Once the signals representative of the real noise produced by aircraft inside the classroom in the open and closed windows configurations have been recorded, the idea is to synthesize and reproduce electro-acoustic signals as close as possible to the real ones**,** considering the effects due to the loudspeaker and to the environment. This goal can be reached by applying the signal processing techniques. Then, the synthesized signals are measured again in the calibration phase at the initially defined microphone position and consequently compared with the originally recorded ones.
The most interesting aspect of this equalization procedure is that it can be applied regardless of the typology of noise to be reproduced.

3.3. Aircraft signal synthesis in presence of virtual windows and reverberation time

Starting from the measured environmental conditions of the classroom under experimental investigation, different conditions of the window are hypothesised and simulated. In particular, windows with different sound insulation characteristics compared to the actual one or different characteristics of the room are considered, simulating reverberation conditions different from those of the real classroom.
Starting from the synthesized signal, with appropriate signal processing techniques using linear filters, it is possible to change the effect of the presence of the real façade sound insulation and adsorption conditions into the virtual ones.

3.4. Final tests

Three typologies of tests have been designed, to be submitted both in a school affected by aircraft noise and specifically located along the take-off and landing airplanes routes and in a school not affected by aircraft noise.
The first test, similar to the one also adopted by the projects referred to in Section 2, focuses on episodic memory and consists in reading a story suitable for the students age inside the classroom. Some moments and words of the reading are disrupted by the reproduction of the aircraft noise signal in the open window configuration. It has been proposed to reproduce the aircraft noise in the open window configuration since it is the most realistic one for mild weather, it represents the worst-case scenario, it offers the better sound to noise ratio and it causes minor problems in phase of questionnaire's submission (especially in case of a concurrent and real aircraft transit). Five minutes after the conclusion of the reading, a questionnaire is submitted to students, asking them to answer to ten questions, five of which are referred to moments of the reading disrupted by the aircraft noise and the remaining five ones to undisturbed moments. The second test consists in the submission of a questionnaire including questions about the personal perception of students about noise in

general, aircraft and road traffic noise, their ability in concentrating also in presence of noise, adjectives suitable/unsuitable for expressing the sensations that noise of various types arouses in them. The third test consists of making students listen to four types of signals played in random order: the signal that reproduces the noise due to the passage of the aircraft in the real conditions of open window at different noise amplitude, the signal that represents the condition of a closed window with the current configuration of façade sound insulation and in presence of virtual conditions of absorption of the internal walls and therefore of virtual values of the reverberation time. Finally, some background information such as the gender and the age distribution of students for each class, together with the percentage of foreign students (in case, of which nationalities) and the number of students with learning difficulties, the economic status of families and the percentage of divorced parents are collected from teachers, after a consultation with parents.

3.5. Methodology application and data analysis

Once the methodology has been defined, each phase has been firstly tested in a school in Florence located at a distance of less than two kilometres from the Vespucci aircraft and along the take-off and landing routes of airplanes.
Subsequently it has been tested in a school located in Prato (Tuscany, Italy) where students are not used to hear noise due to aircraft movements while they are at school.
A total sample of about 300 students aged between 8 and 13 has been identified. Then, starting from the collected data, the most suitable statistical analysis methods will be identified with the final aims of answering to the following questions:

- students who are subject to aircraft noise during school lessons have more problems in listening to a text and understanding it, or are they used to this typology of noise?

- students not used to aircraft noise have more difficulty in understanding the text and perceiving the nuisance of the simulated aircraft noise?

- how different could be the exposure-response curves developed for children if compared to those available for adults?

4. Conclusions

Several studies demonstrate the existence of an association between noise, specifically aircraft noise, and learning disorders in children. Attention, memory and reading skills are all involved in developing the cognitive skills of children of primary school age (5-11 years). Moreover, many social factors seem to be influent on the children's exposure to aircraft noise, such as children’s gender, level of education of children’s mothers, etc.
In addition, annoyance appears to be much more related to aircraft noise than to road traffic noise, due to the fact that aircraft noise is more intense and less predictive than road noise; the nature of the first type of noise tends to distract children more easily and to disturb their attention, while it is easier for them to get used to road traffic noise.
Otherwise, some recent studies demonstrate that children's resilience to aircraft noise could be higher than expected.
Several typologies of cognitive tests (reading comprehension, episodic memory, working memory, prospective memory and sustained attention, long-term memory, etc.) have been submitted to children attending schools located near important aircrafts and the main results are reported by the RANCH, S.Am.Ba and NORAH projects.
However, in all the selected cases, tests have been made during the classroom lessons, within a time frame in which the noise caused by the passage of aircraft could not necessarily be heard.
In this context, the Department of Industrial Engineering of the University of Florence introduces a new methodology aimed at the design of an electro-acoustic system and an on-site replicable listening laboratory, including the processing of audio signals capable of reproducing at fixed times the take-off movement of the aircraft in open and closed window conditions. In this frame, the goal is also to reproduce different environmental configurations or different types of windows, concurrently with the questionnaires submission.
The methodology consists of four main phases addressing: acoustic measurements to be carried inside the classroom in order to register the noise produced by aircrafts in different configuration and to measure the façade sound insulation and the reverberation time, the synthetization of acoustic signals as close as possible to the original ones

generated inside the classroom by aircraft in order to be reproduced during the questionnaire submission, the synthetization of acoustic signals representative of the aircraft noise that would be measured inside the classroom in presence of windows with different performances or reverberation times and the development of three different tests.

The methodology has been firstly applied in a school affected by aircraft noise and successively in a second school not characterized by the same noise problem.

Starting from the data collected in the two schools, in a next future appropriate statistical techniques of analysis will be applied in order to understand if students who are affected by aircraft noise during school lessons have more problems in listening to and understanding a text or if they are used to this source of noise and if students not used to aircraft noise have more difficulty in understanding the text and perceiving the nuisance of a simulated aircraft. Finally, from data collected new dose-response curves are expected to be developed for children.

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