Doctoral Dissertation
Doctoral Program in Management, Production and Design (32th Cycle)

Occupant behaviour as a resource for acoustic comfort.

Validation and evaluation of a device for the reduction of noise generated by occupants in classrooms and offices.

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Oct 22, 2020

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Turin, Oct 22, 2020

Summary

Occupant behaviour has been recognised as one of the key factors able to affect acoustic conditions of indoor and outdoor environments. In particular, high noise levels are mainly generated by occupants in densely occupied environments, such as classrooms, open-plan offices, hospitals and urban spaces, causing negative effects on annoyance, performance and occupant behaviour, as well as on health and well-being. Nowadays, international research community is aware of the key role of occupant behaviour, however the tendency to enclose active engagement of occupants in projects of acoustic improvements is still on a small scale, especially in indoor environments. This limitation is mainly caused by the great effort required by behavioural change interventions, owing to cultural factors, different preferences, priorities and habits.

In this context, a method based on external incentives to encourage more aware behaviours, such as lowering voice levels and changing the room for conversations, is applied in real environments. The key factor of this method is a noise monitoring system with lighting feedback that alternates colours from green, yellow and red according to the change of noise levels, namely SEM (Speech and Sound SEMaphore). It has been designed and patented at Politecnico di Torino in Applied Acoustics Group. An effective validation and impact evaluation of this device and method was still lacking. Therefore, the overall aims of the present PhD dissertation are: 1) to validate SEM device in a densely occupied environments; for this purpose, primary school classrooms and open-plan offices have been adopted as test bench; 2) to evaluate how occupants interact with SEM device and perceive the entire set of external incentives (i.e. paper-based communication, feedback on results provided by researcher, ICT-based solutions); 3) identify a roadmap for the adoption of such complete and qualified system in large-scale applications.

The core methodologies needed for addressing these goals are: 1) field monitoring campaigns to collect objective data; 2) subjective assessments through informal conversational, structured interviews and questionnaires; 3) prototyping and laboratory validation.

This dissertation at a glance

The contents of this PhD dissertation have been developed over the course of the three-year doctoral research.

Some preliminary evaluations based on a first SEM prototype had been carried out by the researchers of the Applied Acoustics Group before the beginning of my PhD research project, with the aim of assessing the viability of the present research project. Such evaluations enlightened a wide field of applicability and, at the same time, enabled to identify some major concerns. Therefore, the PhD research is aimed at filling the gap between the prototype and a product as close as possible to real-life adoption.

This dissertation aims to be a final summary of the different activities carried out during the three years. A great part of the work concerned the development of the new prototype of SEM device using a multidisciplinary approach, as well as the validation of this external incentive in real environments over a long-term period. A part of the validation activity has been carried out in Finland in order to assess the impact of SEM and the underlying methodology in a different cultural environment.

Part of the results has already been shared with the scientific community through conference presentations and the publication on scientific journals. This document has been designed as a monograph explaining in depth each aspect of the research and, at the same time, provide the reader with a comprehensive helicopter view of the whole research. The structure of the dissertation is detailed below through an overview of shortcomings identified in literature and the related research questions addressed.

PART 1: Introduction

The key aspects of **interaction between occupants and outdoor/indoor environments** are introduced from the acoustic perspective. The introduction mainly deals with the analysis of the **state-of-the-art** on the effects related to **noise generated by occupants** in school classrooms and open-plan offices, as well as on the **external incentives** developed to encourage occupant engagement in noise reduction process.

Research gaps and **shortcomings** highlighted in the state-of-the-art are reported as follows:

- **Research gap #1:** presence of few studies on noise effects on a combination of factors, that are annoyance, performance, mental health, well-being and occupants' behaviour with respect to two specific office types: shared and open-plan offices. A particular focus is addressed at differences in perception of a specific noise source, that is noise generated from conversations between colleagues, telephone calls and laughter (irrelevant speech noise) in relation to office sizes and personal characteristics.
- **Research gap #2:** Small scale application of external incentives, such as lighting feedback device, for motivating proactive behaviour towards noise reduction, as well as lack of detailed indications on the effects of these incentives on behavioural change and its fulfilment over a long-term period.

Based on the first research gap identified in the state-of-the-art related to open-plan offices this chapter reports the results of **a cross-sectional survey** carried out in the context of the PhD research project. It is aimed at addressing the following **research questions**:

- **Research question #1:** How do employees evaluate the effects of irrelevant speech noise on annoyance, performance, mental health and well-being, and occupant behaviour in shared and open-plan offices?
- **Research question #2:** Are there relationships between perceived noise annoyance, personal characteristics (i.e. age, gender and professional sector) and office characteristics (i.e. city, number of people in the office and room acoustic design)?

The second family of research gaps is addressed deeply in Chapter 3.

PART 2: SEM (Speech and Sound SEMaphore) device

The **main goals** and the **technical features of the two prototypes** of the noise monitoring system with lighting feedback are presented, with a focus on the attributes and the related requirements of the Beta version of SEM prototype. The **key factors** that make SEM device different from other devices available on the market include the adaptive algorithms for controlling the colours variation of the lighting feedback. Moreover, a focus on **prototyping phase of the Beta version** of SEM device is addressed, as well as the process and outcomes of the **calibration and validation procedures**.

The **shortcomings** highlighted in the existing lighting feedback devices are reported as follows:

- **Shortcoming #3:** The variation of the lighting feedback, that alternates colours from green, yellow and red, is based on pre-set limits of sound levels. The little variation of sound levels, that has a negative impact on human perception, is not taken into account in the pre-set limits.
- **Shortcoming #4:** The external casing of the existing devices is not flexible and customizable according to the intended use and customers' needs.

The fourth shortcoming is addressed in the context of this PhD research project through the prototyping phase of the Beta version of SEM. The prototype also aims to solve the weaknesses of the Alpha prototype emerged during the field monitoring campaign. The prototyping phase is aimed at contributing to answer to the following **research questions:**

- **Research question #3:** Which technical solutions can be applied for solving weaknesses and shortcomings of the Alpha prototype and existing devices, as well as for generating a scalable, accurate, adaptable and customizable prototype in view of the final implementation of the system?
- **Research question #4:** What is the accuracy of the Beta version of SEM prototype in measurement of reliable decibel levels in real environments compared to the 1-class Sound Level Meter?

PART 3: Application of SEM device

This part describes the **procedures**, the **methodologies** and the **outcomes of the application of SEM devices** in both the two prototype versions. The chapter is aimed at addressing the second research gap identified in the first chapter and reported below:

- **Research gap #2**: Small scale application of external incentives, such as lighting feedback device, for motivating proactive behaviour towards noise reduction, as well as lack of detailed indications on the effects of these incentives on behavioural change and its fulfilment over a long-term period.

This part is structured in **two main sections**, **3.1 and 3.2**, **according to the two types of real indoor environments** in which SEM devices were applied, that are **Italian primary school classrooms** and **Finnish open-plan office**.

Section 3.1 – *Long-term monitoring campaigns in primary school classrooms over 3-school years* – is further divided into two parts since the application of SEM devices was linked to the monitoring of teachers' vocal behaviour. The description of each section is following reported with the indication of purpose and research questions.

3.1.1 Monitoring of background noise levels

The application of the Alpha version of SEM device over 3-scholastic years in 13 classes of a primary school in Turin (Italy) is presented. A total of 290 pupils and 25 teachers were involved. These long-term monitoring campaigns are twofold: 1) to understand how occupants interact with SEM devices, and 2) to evaluate whether background noise levels vary according to the presence of the lighting feedback thanks to the behavioural change of pupils and teachers over a long-term period. Objective and subjective investigations were performed. The procedures of the three monitoring campaigns were improved over the years. The monitoring of background noise levels is aimed at contributing to answer to the following **research questions:**

- **Research question #5:** Does SEM device affect the background noise levels generated by pupils?
- **Research question #6:** Can independent variables, such *teacher*, *time-band, number of pupils, day of week* and *class*, significantly affect the background noise levels in the two lighting feedback conditions?
- **Research question #7:** Can the motivational methods, based on constant feedback and/or game-based challenge, encourage pupils towards a long-term behavioural change?
- **Research question #8:** How do teachers assess the acoustic quality of classrooms? How do they perceive the presence of SEM device as an educational tool in classrooms also in relation to pupils' behaviour?

3.1.2 Pilot study: long-term monitoring of teachers' vocal behaviour

This section is a starting point aimed at proposing a methodology based on long-term monitoring of teachers' vocal activity in relation to the presence of the noise monitoring system with lighting feedback. Four school classrooms were involved within the third noise monitoring campaign.

This pilot study is aimed at preliminary contributing to answer the following **research questions**:

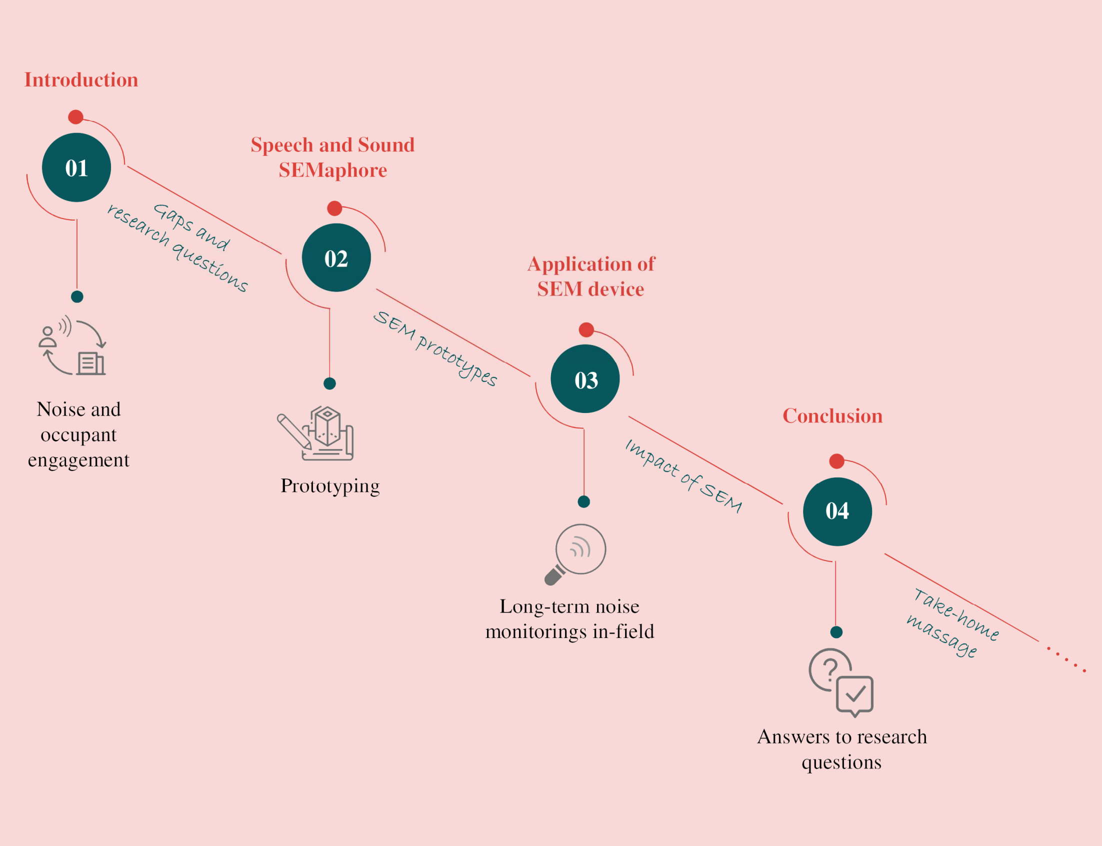
- **Research question #9**: Do the teachers' voice levels decrease when the lighting feedback of SEM devices is switched on in classrooms?

- **Research question #10**: Is there a significant difference in terms of voice levels and background noise levels when SEM devices are switched on, independently from the subjects?
- **Research question #11**: How does SEM device affect the vocal effort of each teacher and the background noise levels, class-by-class?
- **Research question #12**: How do teachers perceive their vocal status, noise condition and voice intensity with and without SEM devices?

Section 3.2 – *Pilot study in a Finnish open-plan office*

This pilot study introduces the application of the Beta version of SEM devices in a Finnish open-plan office with the first aim to propose a methodology to replicate in future works. It also evaluates the functionality of Beta prototypes and the preliminary version of algorithm for office through objective measurements and subjective assessments. Moreover, the investigation on the perception of irrelevant speech noise and on its effects on annoyance, performance, mental health and well-being, and occupant behaviour is addressed to evaluate the intensity of noise disturbance in the investigated open-plan office. In this framework, this section is aimed at preliminary contributing to answer the following **research questions:**

- **Research question #13**: How do employees experience irrelevant speech in the investigated open-plan office?
- **Research question #14**: How and whether does irrelevant speech affect the annoyance, performance, mental health and well-being, occupant behaviour during the working hours?
- **Research question #15**: How do employees perceive the presence of SEM device on their desks during their working activities, as well as its functionality in terms of variation of lighting feedback?
- **Research question #16**: Are there technical issues related to the functionality of the Beta prototype of SEM device?


Introduction
01
Gaps and research questions
Noise and occupant engagement
Speech and Sound SEMaphore
02
SEM prototypes
Prototyping
Application of SEM device
03
Impact of SEM
Long-term noise monitorings in-field
Conclusion
04
Take-home massage
Answers to research questions

List of publications

During the three-years period, part of the results of this PhD dissertation have been disclosed and shared with the scientific community. The contributions are reported below. The reference section is reported for the contributions considered particularly significant in accordance with the contents of the present dissertation. In some publication SEM device is indicated by the original name (Speech & Noise Stop Light; S&N-S Light), that it is change in the context of the PhD research project in order to use a name easier for everyone to understand.

Di Blasio, S.; Shtrepi L., S&N-S LIGHT: *Il dispositivo che controlla il rumore antropico negli ambienti densamente occupati incoraggiando il comportamento adattivo di abbassamento dei livelli di voce*, 44° Convegno Nazionale AIA, Pavia (2017) - Abstract in conference proceedings.

Di Blasio, S.; Calosso, G.; Puglisi, G.E.; Vannelli, G.; Corbellini, S.; Shtrepi, L.; Masoero, M.; Astolfi, A., *S&N-S Light: An anthropic noise control device to reduce the noise level in densely occupied spaces encouraging personal control of voice*, Acoustics '17 Boston - 3rd Joint Meeting of the Acoustical Society of America and the European Acoustics Association - Conference paper.

Di Blasio, S.; Vannelli, G.; Shtrepi L.; Masoero, M.C.; Astolfi, A., *A subjective investigation on the impact of irrelevant speech noise on health, well-being and productivity in open-plan offices*; Euronoise 2018, Crete (2018) - Conference paper.

Di Blasio, S.; Puglisi, G.E.; Shtrepi, L.; Corbellini, S.; Castellana, A.; Vannelli, G.; Astolfi, A., *S&N-S Light: an innovative educational tool that controls chatting noise levels in classrooms by encouraging pupils to change their behaviour*, Euronoise 2018 Crete (2018) - Conference paper.

Di Blasio, S.; Puglisi, G.E.; Shtrepi, L., *Uno strumento innovativo per incoraggiare gli studenti di una scuola primaria verso un comportamento adattivo utile a ridurre i livelli di rumore di fondo*, 45° Convegno Nazionale AIA, Aosta (2018) - Conference paper.

Di Blasio, S.; Shtrepi, L.; Puglisi, G.E.; Astolfi, A., *A cross-sectional survey on the impact of irrelevant speech noise on annoyance, mental health and well-being, performance and occupants behavior in shared and open-plan offices*, Int J Environ Res Public Health. 2019 Jan 19;16(2). pii: E280. doi: 10.3390/ijerph16020280. - Scientific Article.

PART 1: **Introduction**, **Section 1.2.2.2** – *Open-plan offices* – **Section 1.3.** – *Noise generated by occupants: a cross-sectional survey performed in shared and open-plan offices.*

Di Blasio, S.; Puglisi, G.E.; Gervasi, C.; Castellana, A.; Murgia, S.; Minelli, G.; Vannelli, G.; Corbellini, S.; Carullo, A.; Astolfi, A.; *A pilot study in primary school on the effect of noise monitoring system with lighting feedback on teachers voice parameter, noise levels and subjective assessments*, International Congress on Acoustics - ICA 2019, Aachen (2019) - Conference paper.

PART 3: **Application of SEM device**, **Section 3.1** – *Long-term monitoring campaigns in primary school classrooms* – **Section 3.1.3** – *Pilot study: long-term monitoring of teachers' vocal behaviour.*

Aletta, F.; Molinero, L.; Astolfi, A.; Di Blasio, S.; Shtrepi, L.; Oberman, T.; Kang, J.; *Exploring associations between soundscape assessment, perceived safety and well-being: a pilot field study in Granary Square, London*, International Congress on Acoustics - ICA 2019, Aachen (2019) - Conference paper.

Di Blasio, S.; Vannelli, G.; Shtrepi, L.; Puglisi, G.E.; Calosso, G.; Minelli, G.; Murgia, S.; Astolfi, A., *Long-term monitoring campaigns in primary school: the effects of noise monitoring system with lighting feedback on noise levels generated by pupils in classrooms*, INTER-NOISE 2019, Madrid (2019) - Conference paper.

PART 3: **Application of SEM device**, **Section 3.1** *Long-term monitoring campaigns in primary school classrooms* – **Section 3.1.2** – *Monitoring of background noise levels.*

Acknowledgment

My PhD path has been an incredible opportunity and experience of personal and academic growth. I want to thank all the people that supported me during these years.

First, I would like to thank my supervisor, Prof. Arianna Astolfi, for igniting in me the passion for research. Thank you for the rewarding discussions and lessons learned on an academic and personal standpoint. Thank you for believing in my skills and supporting me throughout my PhD journey, motivating me to bring it to completion.

A big thank you also goes to Louena for being such an important mentor and friend; you have opened up the world of research for me during my Master thesis work and continued to support me during my personal and academic growth, despite a change in the topic from what we had originally planned. Thank you for pushing me to carry on even when the research results were not already convincing yet.

I am also grateful to Gianluca for the time and commitment dedicated to my PhD thesis. Thank you for helping me improve the whole manuscript. My gratitude to you is incommensurable.

A special thank you goes to Cristina for being my adventure mate during the whole PhD journey inside and outside of the office. These years would not have been the same without you. Thank you for your lovely support during the last stressful

months of the thesis writing: our working days spent in the library and our “sweet” coffee breaks are memories I will always cherish. Now it is time to thank to Andrea: these years would have not been as funny without you in the office. We made a great team.

Thanks to Giusi and Antonella for the quality time spent together at work and outside, in particular a very special thank you goes out to Giusi for arousing my curiosity towards in-field research in classrooms. A massive thank you to Greta, Elena and Matteo for being such lovely co-workers but mostly for being good friends.

I also would like to thank my wonderful friend, Ilaria. You helped me shape a resilient mindset towards the hardships of academic life and supported me during my personal and professional growth. Thank you for sharing fun moments, as well as stressful ones.

A big thank you goes to Beppe for his support in all technical and in-field activities (puffing and muttering). I know that without your help I would have never achieved these results.

Thanks to Alessia and Stefano for believing in the SEM project. Although the collaboration between the Applied Acoustics Team and their companies had started before my PhD activities, they have warmly welcomed me and shared their knowledge and time, making it a truly remarkable working experience.

I also would like to thank Prof. Valtteri Hongisto and Senior Researcher Jenni Radun for widening my research perspective on top of making me feel welcomed when I was at the Turku University of Applied Sciences in Finland.

Also, I would like to thank my best friends, Silvia and Denise for being my point of reference. You have both been there for me and always supported me during my personal growth. Thanks to Luca for believing in my skills and helping me out during my first moments in Turin.

A special thank you goes to Claudio. Your presence in my life is a precious source of joy. You have shaped my vision of life showing me the things from completely different angles. I am thankful for that.

A unique thank you goes to my family for the devoted and unconditional support. Without my parents this would have never been possible: they gave me strength every step of the way.

I would have never achieved this result without the support of all of you. Thank you for being good supervisors, co-workers and, especially, wonderful friends.

To my loving
parents, Paolo and
Emilia.

Contents

List of Tables

List of Figures

PART 1

Introduction

Overview

The introductory chapter provides a general overview on how the **energy research community is dealing with the behaviour** of occupants and a brief indication of the external incentives that have been developed to achieve energy efficiency goals.

Moreover, the discussion is focused on the **current issues related to noise generated by occupants** in outdoor and indoor environments, mainly pertaining to **school classrooms** and **open-plan offices**. The results of a **cross-sectional survey** are reported in order to focus on the impact of noise generated by occupants on subjective perceptions, regarding annoyance, performance, occupants' behaviour, mental health and well-being, in shared and open-plan offices.

Furthermore, an overview of the **external incentives** adopted to **motivate and assess behavioural changes** towards noise reduction is given. The overview focuses in particular on **lighting feedback systems** in which sound level variations are represented through variations in coloured lights.

1.1 Interaction between occupants and outdoor/indoor environments

Attention to the behaviour of occupants is continuously increasing, since the scientific community is well-aware of the fact that the interaction of occupants with building systems tends to influence the building energy demand as well as the indoor environment, both directly and indirectly (Masoso and Grobler, 2010). Occupants tend to undertake adaptive actions to attain their personal comfort and satisfy their needs: these include both adapting the environment to personal needs (e.g. adjusting heating/cooling set points and lighting levels, as well as the window and sunscreen conditions) and adapting personal behaviour to the environment (e.g. changing the room, moving through a space, raising voice levels) (Dear et al., 1998). Apart from this, non-adaptive actions can also be taken: for example, certain behaviour can be triggered by external feedbacks, such as from lighting feedback systems that alternate green, yellow and red colours, according to changes in noise levels in an environment.

Research on occupants' behaviour is continuously growing in the energy and building academic communities: the number of studies on this topic shows an increasing trend, as it has been conceived as a key factor for the optimisation of building design, energy diagnosis and building energy simulation (Yan et al., 2017). The research efforts deal with this topic from different perspectives: on the one hand, novel occupant behaviour models are being developed to reduce the uncertainty due to the stochastic nature of the occupant-building interaction (Yan et al., 2017); on the other hand, external incentives and awareness campaigns are being studied to actively engage occupants in reaching energy efficiency goals (Barthelmes et al., 2019; Cottafava et al., 2019; Fabi et al., 2016). This topic is considered of greater interest for the aims of the present dissertation, and a brief overview of the external incentives used in the building research community is therefore reported in Section 1.4.

The behaviour of occupants can also affect the acoustic conditions of indoor and outdoor environments. For example, noise generated by occupants is largely perceived as the most disturbing noise source in densely occupied environments, such as classrooms, open-plan offices, hospitals and urban spaces. It has also been proven that this noise source generates negative effects on psychosocial and economic factors, as well as on the health and well-being of occupants, as discussed in the following sections. Nonetheless, despite this, investigations on the interaction of the behaviour of occupants with the acoustic environment are still scarce. The studies on alternative solutions, based on an active engagement and more aware behaviour of the occupants are still somewhat limited, especially for indoor environments.

The remainder of this chapter is aimed at introducing and discussing the following topics:

- The effects of noise generated by occupants in densely occupied environments: the results of a state-of-the-art research are presented, with particular focus on school classrooms and open-plan offices.
- The impact of noise generated by occupants in shared and open-plan offices: the results of a cross-sectional survey are presented with the aim of addressing the research gaps and shortcomings revealed by a literature review.
- Systems based on external incentives: a state-of-the-art research on solutions aimed at improving acoustic comfort and encouraging proactive behaviour is presented, with particular focus on visual feedback systems. The research gaps and shortcomings are also reported.

1.2 Noise generated by occupants: state-of-the-art

The available literature agrees that high noise levels and noise annoyance are mainly generated by the occupants of indoor and outdoor environments frequented by a large number of people. In order to provide a comprehensive picture of this topic, a brief overview on noise problems generated by occupants in urban spaces and in indoor spaces is reported; a detailed discussion on this complex phenomenon, focused on classrooms and open-plan offices, is then provided.

1.2.1 Outdoor environments

When considering **urban spaces**, the research community has mainly investigated the effects of exposure to noise generated by transportation, industrial activities and neighbourhood actions on human health and well-being. Currently, European cities are affected by a new phenomenon, denoted by the Spanish term *movida*, which indicates the collective use of areas and establishments for nightlife activities, as reported in the Horizon 2020 “MONICA” project (https://www.monica-project.eu).

In the recent guidelines on the protection of human health, the World Health Organisation (WHO) has added *leisure noise*, which is defined as “noise sources that people are exposed to due to leisure activities, such as attending nightclubs, pubs, fitness classes, live sporting events, concerts or live music venues and listening to loud music through personal listening devices”, to the list of environmental noise sources (Brown and van Kamp, 2017).

On one hand, the movida is certainly a resource that makes towns alive and increases their economic and social values. On the other hand, it is considered as an emergency for the public order due to the resulting social and economic issues, such as noise pollution, huge alcohol/drug consumption, large crowds and conflicts between different stakeholders (Gallo et al., 2018; Ottoz et al., 2018). Leisure noise also negatively affects the perceived annoyance, health and well-being of people and can lead to cardiovascular diseases, sleep disturbances and, consequently, poor performance at work, fatigue, memory difficulties and concentration problems during one’s daily life (Asensio et al., 2018; Brown and van Kamp, 2017).

In this framework, the international research community is dedicating a great deal of effort to short- or long-term monitoring campaigns, subjective assessments and citizen engagement in the movida districts affected by leisure noise (Adina et al., 2019; Asensio et al., 2018; Farrés, 2015; Fimiani and Luzzi, 2015; Gallo et al., 2018; Ottoz et al., 2018; Vinci et al., 2017).

Gallo et al. (2018) performed both temporary and long-term monitoring campaigns in the movida districts in Turin: they found noise levels of between 58 dB(A) and 72 dB(A) during weekend nights (11 pm to 3 am), which exceed the limits set for the local noise zoning ranges. Asensio et al. (2018) found similar results in Malaga, where the noise levels ranged between 60 dB(A) and 80 dB(A) on summer nights (11 pm to 7 am) in leisure areas.

Researchers are promoting several strategies aimed at coping with leisure noise, such as the adoption of noise monitoring networks based on the Internet of Things technology, awareness campaigns and participative strategies for citizen engagement. An overview of these external incentives, proposed within international research studies and Horizon 2020 projects, is provided in Section 1.4.

1.2.2 Indoor environments

The noise generated by occupants is one of the most disturbing noise sources in **indoor spaces**: it impacts the acoustic comfort, performance, health and well-being of people.

Currie (2014) performed a study on hospital environments: unwanted sound, which includes noise coming from patients and from the staff talking or laughing, was found to be a frequently recognised problem by patients. A correlation between sound levels and indicators of perceived stress was found for the perception of staff and for physiological measures (Blomkvist et al., 2005; Morrison et al., 2003). Brown et al. (2016) investigated the impact of different strategies to reduce noise in wards for older, adult, mental-health patients, such as the addition of relaxing background music and the introduction of external incentives based on the engagement of the nursing staff. The outcomes highlighted the key role of staff involvement in making a project successful.

Classrooms and open-plan offices were selected here as a starting point for the validation of SEM devices. These are densely occupied spaces where the turnover of occupants is low, which made it possible to use SEM over the entire working period. A detailed investigation of problems generated by human speech in **classrooms** and **open-plan offices** is presented in the following sections.

1.2.2.1 School classrooms

Classroom acoustics may generate challenging environments for both students and teachers, as it influences the performance of students, speech intelligibility and the vocal effort made by teachers in order to be understood by pupils.

Subjective assessments and objective measurements of the perceived noise annoyance and of the frequently perceived sound sources in classrooms have been carried out by the international research community.

On the basis of a survey conducted in primary and secondary schools, Bottalico and Astolfi (2012) and Astolfi and Pellerey (2008) found that students talking and moving around the classroom were the highest perceived sources of noise in classrooms, and that noise disturbance and noise intensity were closely correlated with students talking. Conversation and chatting are also key factors that affect the listening environment in university classrooms, according to students, as reported in Kennedy et al. (2006). Shield and Dockrell (2004), on the basis of objective measurements on a large sample of primary school classrooms in London, found that high noise levels were generally caused by pupils and teachers. Sato and Bradley (2008) showed an increase in the average noise levels of up to 10 dB(A) caused by pupils during teaching activities in Canadian primary schools.

Over the years, several studies have been conducted to characterise the indoor environments of schools through objective measurements of classroom noise. Shield and Dockrell (2004) found that the typical background noise levels (L_{A90}) ranged from between 42 dB(A) and 64 dB(A) in classrooms, depending on the type of activities conducted. Sato and Bradley (2008) measured lower ambient noise levels in occupied classrooms without student activities: the mean values were found to be around 49 dB(A). In their investigation of teachers' vocal doses, Bottalico and Astolfi (2012) analysed 41 Italian classrooms and found average background noise levels ranging from between 50 dB(A) and 53 dB(A) during traditional lessons. Higher background noise level values – of around 56 dB(A) – were measured when entire lessons (around 4 h) were measured in four different schools in Italy (Puglisi et al., 2017).

Several studies have focused on the detrimental effects generated by poor classroom acoustics, in terms of reverberation time and background noise levels on the performances of pupils and teachers (Choi and McPherson, 2005; Klatte et al., 2013; Massonnié et al., 2019; Prodi et al., 2019; Shield and Dockrell, 2008), on speech intelligibility (Astolfi et al., 2012; Bradley et al., 1999; Prodi et al., 2013), as well as on health and well-being (Bottalico and Astolfi, 2012; Calosso et al., 2017; Kristiansen et al., 2014, 2016).

A significant decrease in performance in non-verbal and verbal tasks, such as reading and spelling, has been found in cognitive tests performed in primary school classrooms when the background noise level interferes with speech. Noise generally influences older primary school pupils (around 11 years old) more than younger ones (Shield and Dockrell, 2008). A loss of concentration and a decrease in teachers' speech comprehension have been perceived by students in secondary and university school classrooms (Astolfi and Pellerey, 2008; Kennedy et al., 2006). The level of involvement in classroom activities has been found to be negatively affected by high noise levels, especially in primary schools (Choi and McPherson, 2005). During the pedagogical activities performed inside forty-seven primary classrooms, the ability of younger pupils (5-8 years old) to generate original ideas was affected by moderate classroom noise, that is, noise equal to 64 dB (Massonnié et al., 2019).

From the teachers' perspective, classrooms are challenging environments as they have to raise their vocal effort in order to maintain a high intelligibility in noisy conditions and when there are poor classrooms acoustics. This vocal behaviour of teachers is known as the Lombard Effect, which is defined as "the involuntary tendency of speakers to increase their voice level when speaking in loud noise to enhance the audibility of their voice" (Harlan and Bernard, 1971).

Most of the available studies have so far dealt with the effects of different acoustic environments on the vocal behaviour and health symptoms of teachers, focusing on the effect of noise (Bottalico and Astolfi, 2012; Kristiansen et al., 2014), on the talker-to-listener distance (Cheyne et al., 2009; Michael et al., 1995; Pelegrín-García et al., 2011) and on reverberation (Calosso et al., 2017; Kristiansen et al., 2016).(Kristiansen et al., 2016) found that an improvement in the reverberation time, generated by the acoustical refurbishment of thirty-six classrooms, led to a reduction in the teachers' perceived noise exposure; nonetheless, their voice symptoms and fatigue were not significantly affected. Kristiansen et al. (2014), in a previous study, measured a rise in the voice load ($L_{Aeq,vocal}$) of 0.65 dB(A) for a 1 dB(A) increase in classroom noise. Moreover, the teachers self-reported an increase in voice symptoms over the working time and cognitive fatigue after work, as a consequence of exposure to noise.

Most of the literature so far mentioned adopted air-microphones to measure the sound levels and, in turn, to estimate the vocal effort. Recent studies have adopted a new, portable measurement device to improve the accuracy of data collected through in-field investigations. This device is a vocal analyser which is capable of measuring the vibration of the skin at the speaker's neck and of estimating vocal parameters, but it has a negligible sensitivity to background noise (Carullo et al., 2013, 2014; Carullo, Casassa, et al., 2015; Carullo, Vallan, et al., 2015). A detailed description of this measurement device is reported in Section 3.1.3. Using this device, Bottalico and Astolfi (2012) found a 0.72 dB increase in the mean sound pressure level at 1 m from a teacher's mouth for a 1 dB increase in the noise level. This increase in voice level was found during traditional lessons – i.e. when the teacher faces the students – in primary school classrooms with different reverberation time values. Puglisi et al. (2017), who considered the entire working day (4 h) of primary school teachers, found a 0.53 dB increase in speech level for a 1 dB increase in noise level (L_{A90}), and the background noise levels generally ranged between 50 dB(A) and 70 dB(A).

In addition to classroom environment, other factors, such as personal factors (i.e. gender, age, voice status, hearing sensitivity, speaking experience or training, physical conditions and feelings) may influence speech production (Astolfi et al., 2019). Furthermore, voice disorders have been proven to be impacted by poor acoustic environments as well as by an incorrect use of the voice. Åhlander et al. (2012) found that the interplay between personal behaviour and the work environment is the main cause of voice dysfunctions for teachers that self-reported voice problems. As suggested by Kristiansen et al. (2016), acoustic interventions, to reduce background noise levels in classrooms, should be taken for both the physical properties and the occupants' behaviour, even though the latter aspect requires a great deal of effort.

Nonetheless, classroom layouts and educational methods are both evolving, and new challenges are arising. A conversion from traditional to open-plan classrooms is currently taking place. This process began in 1970, when the layout of learning environments began to change to facilitate team work and skill sharing, and to improve the feeling of safety (Mealings et al., 2015). This attempt was quickly abandoned, due to the negative effects generated by an open layout, including high noise levels caused by a large number of students in the same area (Shield et al., 2010). However, this paradigm has come back in recent school building programmes, e.g. the United Kingdom's Building Schools of the Future 2003-2010 programme: the re-designing of schools involves moving towards open classrooms and open models of learning. In this framework, the international research community has been dedicating a great deal of effort to the evaluation of noise effects in this kind of classroom. Speech perception tests, performed in four kindergartens with different open layouts by Mealings et al. (2015), showed that the accuracy and speed of the performance of pupils tended to decrease during noisy activities. They also indicated that fully open-plan classrooms could not be a proper learning space if they lacked a good acoustic design, which should be based on a variety of spaces and be able to face the emerging needs of different learning activities. According to Leahy et al. (2019), smart materials and sensory structures could be the key tools to reduce the noise problems that emerged 50 years ago, during the first development phase of open-plan classrooms. However, they highlighted the need to dedicate research efforts to proposing methodologies in order to prepare teachers and students to interact with the new learning space configurations. These results show that the criticalities related to noise generated by students' behaviour, e.g. conversations, the movement of chairs, the rustling of paper and the noise from falling objects, have been acknowledged and investigated in traditional classrooms, as well as in the future concept of classrooms based on an open layout. The possibility of involving students and teachers in improving the acoustic comfort of classrooms by encouraging behavioural changes is promising and should be further investigated, even though this method requires a great deal of effort and conflicting results could be obtained due to cultural factors, as well as to different preferences, priorities and habits.

1.2.2.2 Open-plan offices

In the international research community, Irrelevant Speech Noise (ISN) is known to be the most disturbing source of noise (Banbury and Berry, 2005; Hedge, 1982; Kaarlela-Tuomaala et al., 2009; Perrin Jegen and Chevret, 2017; Pierrette et al., 2018) perceived by employees in open-plan offices due to the overall noise level and intelligible conversations (Hongisto, 2005; Jahncke et al., 2011; Schlittmeier and Liebl, 2015). ISN is defined as noise generated from conversations between colleagues, telephone calls and laughter (Kaarlela-Tuomaala et al., 2009; Kang et al., 2017). In agreement with the open-plan office literature, the term "irrelevant speech noise" is used in this thesis to denote the noise generated by the occupants of such spaces.

In line with the classroom research field, several studies have dealt with the effects of noise in offices on different factors, such as annoyance, performance, mental health, well-being and occupant behaviour. An overview on the state-of-the-art related to these themes is presented hereafter.

First, a self-estimated loss of performance, due to ISN, has been found in open-plan offices through subjective assessments (Jensen KL. 2005; Haapakangas et al., 2008; Kaarlela-Tuomaala et al., 2009; Mak and Lui, 2012; Perrin Jegen and Chevret, 2017). The same finding emerged from the results of laboratory studies, where subjective perceptions were investigated and tests based on several cognitive tasks were performed (Haapakangas et al., 2014; Jahncke et al., 2011; Martellotta et al., 2011; Schlittmeier and Liebl, 2015; Varjo et al., 2015).

Furthermore, a great amount of research has been addressed to better understanding how office noise is related to the mental health and well-being of the occupants. According to the WHO ("North West Mental Wellbeing Survey", 2012), mental health is a state of well-being in which the individual realises his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community. On the other hand, mental well-being has been defined as simply feeling good and functioning well (Keyes, 2002). The consequences of mental health problems in the workplace were indicated by WHO (Shephard, 2002) as follows: depression, stress, burnout, but also headaches, ulcers, high blood pressure, reductions in productivity and output, losses of motivation and commitment, tension and conflicts between colleagues.

In this framework, several symptoms, such as fatigue and headaches (Kaarlela-Tuomaala et al., 2009; Pejtersen et al., 2006), difficulties in concentration (Banbury and Berry, 2005; Kaarlela-Tuomaala et al., 2009; Pejtersen et al., 2006; Perrin Jegen and Chevret, 2017), physiological stress (Evans and Johnson, 2000), loss of motivation and tiredness (Jahncke et al., 2011) and increased cognitive workload (de Croon et al., 2005) have been noted in open-plan offices. Jahncke et al. (2011) showed that the self-rating of the tiredness and motivation of subjects decreases for high noise levels, compared to low noise levels. Fatigue, headaches and difficulties in concentration are related to the size of the office, as found by (Pejtersen et al., 2006). According to (de Croon et al., 2005), the openness of a workplace and the distance between workstations are causes of increased cognitive workloads. Pejtersen et al., (2006) and Danielsson, (2005) reported an increased absence, due to sickness, from open-plan offices. Psychological health was perceived differently by employees in different offices grouped according to the type of work done in such offices (Perrin Jegen and Chevret, 2017).

A great research effort has been made to evaluate how room acoustic solutions, such as sound absorption materials, screens between workstations (Haapakangas et al., 2014; Hongisto et al., 2016; Schlittmeier and Liebl, 2015; Seddigh et al., 2015) and sound masking systems (Haapakangas et al., 2011, 2014; Renz et al., 2018; Schlittmeier and Liebl, 2015) can be applied in offices to improve the acoustic conditions and reduce the noise levels. Haapakangas et al. (2014) found that the disturbance caused by intelligible background speech can be reduced by an optimal and accurate acoustic design of the office when the speaker and listener are at least four-to-six meters away from each other. However, according to Hongisto et al. (2016), very little is actually known about the effects of room acoustics on the reduction of ISN.

In response to the dissemination of open-plan offices against private offices, researches have been carried out to compare the noise perception in these extreme office types (Haapakangas et al., 2008, 2018; Kaarlela-Tuomaala et al., 2009; Sundstrom et al., 1982; Zalesny and Farace, 1987). Comparative information about different office types has been investigated in other researches, which were mainly based on subjective surveys rather than objective measurements, such acoustical measurements and cognitive tasks. Focusing on the latter, Danielsson et al. (2015) investigated the relationship between the office type and workplace conflicts, in particular with reference to noise. They pointed out that conflicts between colleagues can in part be attributed to the differences in exposure to noise between office types. A multi-domain approach, that considered the combined effects of two or more ambient factors, i.e. indoor air quality and thermal, visual and acoustic domains (Schweiker et al., 2020), has been used to evaluate workspace satisfaction (Kim and de Dear, 2013; Sakellaris et al., 2016), perception (Pejtersen et al., 2006) and annoyance (Bodin Danielsson and Bodin, 2009) of office occupants. Although noise is included among the ambient factors in these studies, it was not the primary interest in the investigations. Moreover, Chao et al. (2003) and Brennan et al. (2002) only dealt with the effects of noise in the work environment to a very limited extent. Ayr et al. (2001) and Mak and Lui (2012), who conducted research on different types of offices, did not report the results on noise-related questions separately. Perrin Jegen and Chevret, (2017) evaluated the self-estimated effect of noise on a combination of different factors, that is, annoyance, health and well-being, interpersonal relationship and performance, with respect to the size of offices. To the best of the author’s knowledge, this is the only study on noise effects that considered the combination of different factors, although the number of employees per each office type was not reported.

1.3 Noise generated by occupants: a cross-sectional survey performed in shared and open-plan offices

In response to the above-mentioned limitations and the presence of just a few studies on noise effects in relation to different factors simultaneously, the cross-sectional survey presented in this section was aimed at providing new knowledge on the self-estimated impact of a specific noise source (Irrelevant Speech Noise) on a combination of factors, that is, annoyance, performance, mental health, well-being and occupants' behaviour with respect to two office types. The choice of comparing shared (2–5 occupants) and open-plan (+5 occupants) offices (Hongisto et al., 2016) arose from the consideration that shared offices can be an alternative to very noisy open-plan offices in order to continue encouraging cooperation and knowledge-sharing between workers.
As the importance of involving the occupants in densely occupied environments, in order to reduce the noise levels, has emerged in the literature, the cross-sectional survey has had the aim of evaluating the willingness of the occupants to use a noise monitoring device with light feedback in order to keep the noise levels in open-space offices under control. The purpose of such systems, according to Hongisto et al. (2016), is that they can reduce speech disturbance by lowering the voice effort. Bradley (2003) considered that office etiquette was a successful way of encouraging the use of low voice levels in open-plan offices, while Schlittmeier and Liebl (2015) affirmed that social conventions, such as defined silent times and phone times, can help to limit noise levels resulting from speech in open-plan offices.

The cross-sectional survey was aimed at addressing the following **research questions**:

- How do employees evaluate the effects of ISN on annoyance, performance, mental health and well-being, as well as occupant behaviour in shared and open-plan offices?
- Are there any relationships between the perceived noise annoyance, personal characteristics (i.e. age, gender and professional sector) and office characteristics (i.e. city, number of people in the office and room acoustic design)?

The methods and results of the cross-sectional survey are presented in the following sections, since the themes related to noise problem generated by occupants in indoor and outdoor environments are described in this first chapter. The contents of this section have been published in the paper: *"A cross-sectional survey on the impact of irrelevant speech noise on annoyance, mental health and well-being, performance and occupants behavior in shared and open-plan offices"* (Di Blasio et al., 2019).

1.3.1 Subjects and methods

The cross-sectional survey was performed in Italy: nineteen companies, that is, eleven small companies and eight large ones, five research centres and one university were involved. The selected offices differed as far as the city, professional sector, office layout and design of the room acoustics are concerned. The location of the cities has in particular been considered in the present study since there is evidence of multiple socio-economic-cultural variables that characterise the north-south differential (Carboni and Russu, 2018).

A total of 6752 employees were invited to respond to an online questionnaire from September to November 2017. Of this number, 1180 employees responded, thus a response rate of 17.5% was achieved, which is in line with the response rate of online questionnaires (Nulty, 2008).The responses of 102 employees who worked in private offices were excluded, in line with the purpose of the study, which was aimed at investigating the effects of ISN inside offices. Indeed, the source of noise in private offices is mainly generated by speech sounds from outside the office and/or useful speech from colleagues visiting the office. Consequently, 1078 out of the 1180 responses were taken into account in the analysis based on the completed questionnaire; in fact, only the completed questionnaires were registered in the database. The total sample (N = 1078) was split into two sub-samples: sample 1) (S) included answers from employees working in shared offices while sample 2) (O) referred to open-plan offices. The corresponding percentages were about 55% (597 employees) in the shared offices and about 45% (481 employees) in the open-plan offices.

As far as the characteristics of the occupants are concerned, 55% of them worked in universities, 3% in research centres, 41% in companies and 1% of them were freelance. Regarding the professional sectors, 28% of the employees came from engineering areas, 21% from technical sectors and 27% from the administration sector. The respondents were 58% male and 42% female. The subjects mainly worked in Turin, with a percentage equal to 78%. The total sample was mainly distributed over three age ranges: 26–35 (33%), 36–50 (26%) and 51–65 (36%) years of age. The subjects worked in three different types of office: 55% in shared offices, 43% in medium-sized open-plan offices and 1% in large open-plan offices. The background information of the data samples is reported in Table 1.

1.3.2 Questionnaire

The questionnaire was designed through Google Forms (https://www.google.com/forms/about/) and administered using an online link distributed by e-mail. It was approved, via the ethics review procedure, by the Politecnico di Torino, and it was also accepted by the head of the human resources of each company.

Table 1. Main characteristics of the total sample (N = 1078) divided into shared and open-plan offices. The percentages of the two samples are indicated in brackets.

Background Information		Shared Offices	Open-Plan Offices
Gender	Female	269 (45)	188 (39)
	Male	328 (55)	293 (61)
City	Milan	11 (2)	28 (6)
	Turin	464 (78)	378 (79)
	Cuneo	5 (1)	10 (2)
	Rome	27 (5)	31 (6)
	Naples	88 (15)	34 (7)
	Other	2 (0)	0 (0)
Age range	18–25	23 (4)	26 (5)
	26–35	170 (28)	182 (38)
	36–50	187 (31)	98 (20)
	51–65	212 (36)	175 (36)
	65+	5 (1)	0 (0)
Professional sector	Technical	118 (20)	104 (22)
	Engineering	177 (30)	124 (26)
	Management	42 (7)	37 (8)
	Administration	152 (25)	139 (29)
	Creative, design and architecture	46 (8)	30 (6)
	Sales and public affairs	9 (2)	20 (4)
	Teaching	4 (1)	2 (0)
	Other	49 (8)	25 (5)
Number of people in the offices	From 2 to 5 (shared)	597 (55)	-
	From 6 to 20 (medium-sized open-plan)	-	467 (43)
	From 21 to 200 (large-sized open-plan)	-	14 (1)

An accompanying letter was added to the e-mail in order to inform the subjects about the confidential treatment of their personal data, the anonymity of the answers and to establish their voluntary participation in the survey.

A total of 17 questions were included in the questionnaire, which was available in both Italian and English versions. The importance of avoiding overtaxing and high dropout rates because of boredom led to the development of a short questionnaire: less than 5 minutes was needed to fill it in. It was composed of 3 sections: 1) an explanation of the aim of the survey and the response time, 2) background questions, and 3) subjective opinions. The aim of the study was explained in the letter accompanying the first section and the definition of ISN was provided, i.e. *the noise generated from conversations between colleagues, telephone calls and laughter* (Kaarlela-Tuomaala et al., 2009; Kang et al., 2017). However, the term *chatting noise* was used in the questions instead of *Irrelevant Speech Noise* as it is a more common term and it is easier to understand by lay respondents. General information about the gender, age, nationality, company and professional sector was collected through the seven background questions.

Table 2 shows the 10 questions in the third section, as well as the topics addressed in the questionnaire: annoyance (Q1), mental health and well-being (Q2 and Q6), productivity (Q3–Q5) and occupant's behaviour (Q7 and Q10). A single choice question was used regarding mental health and well-being in Q2, in which a list of feelings and symptoms was presented to the subjects (Fellin, 1996; "North West Mental Wellbeing Survey About Public Health England", 2012; Shephard, 2002): (1) mental illness, such as stress, (2) loss of concentration, (3) emotional and social feelings, such as feeling displeased, loss of motivation, anger, negative feelings towards colleagues, and (4) physical symptoms, such as tiredness, overstrain and headaches. Since mental health and well-being are closely related to interpersonal relationships ("North West Mental Wellbeing Survey", 2012), Q6 was aimed at investigating this aspect. The behavior an occupant adopted to cope with ISN was assessed in Q7 and Q10. Q7 in particular investigated the personal strategies used to reduce annoyance resulting from people chatting, which were summarised as follows: (1) the use of technological tools, such as headphones with music and noise cancelling headphones, (2) the use of adaptive behaviour (Dear et al., 1998; Nicol and Humphreys, 2002), such as taking a break, changing the work space, changing the work task, working from home and closing the office door, and (3) asking colleagues to reduce their voice levels. As a further feature of the occupant's behaviour, the willingness of employees to be actively involved in the reduction of ISN, by lowering their voices when advised by a lighting feedback system, was investigated in Q10. Two additional questions (Q8 and Q9) were included in the questionnaire to investigate the perceived presence of acoustic treatments in the offices.

The content of the questionnaire was defined explicitly according to the purpose of the study. The wording of the questions, as well as the Likert scale ranking, treated as an interval scale, and the list of alternatives were drawn up on the basis of previous studies. The reference studies for each question are reported in Table 2. The single choice questions, that is, Q2 and Q7, were included according to (Ortalda, 1998; Converse and Presser, 1986) in order to investigate the main feelings or symptoms and the main personal strategies adopted to cope with ISN. Two questions, Q3 and Q6, were presented in an affirmative version and the employees were asked to indicate their level of agreement. Three questions (Q8, Q9, Q10) were new compared to previous studies, and the list of alternatives in Q9 were defined considering the acoustic treatments commonly used in offices. The options in Q2, Q7 and Q9 were presented to the subjects randomly.

Table 2. Questionnaire layout.

Topic	ID	Question	Scale	Labels	Ref.
Annoyance	Q1	How much does people chatting in your office annoy you?	5	Not at all (1) Extremely (5)	Haapakangas et al., 2011; Hongisto et al., 2016
Mental health and well-being (feelings and symptoms)	Q2	What is the main feeling (or symptom) related to people chatting during your work tasks?	Single choice	Loss of concentration/ Loss of motivation/ Tiredness and overstrain/ Stress/ Anger/ Negative feelings such as feeling displeased/ Negative feelings toward other colleagues/ Headache/ None/ Other	Kaarlela-Tuomaala et al., 2009; Pejtersen et al., 2006; Shephard, 2002
Work productivity	Q3	People chatting around me often interrupts me during my work tasks	5	Strongly disagree (1) Strongly agree (5)	Haapakangas et al., 2011; Hongisto et al., 2016
	Q4	People chatting does not allow me to work as much as I would like to			
	Q5	People chatting around me significantly reduces my work performance			
Mental health and well-being (interpersonal relationships)	Q6	People chatting compromises the harmony of the entire office	5	Strongly disagree (1) Strongly agree (5)	
Occupants behaviour (Personal strategies)	Q7	What is the main strategy that you use to reduce the annoyance resulting from people chatting?	Single choice	Change working space or room/ Headphones with music/ Noise cancelling headphones/ Ask people to reduce voice/ Change work task/ Work from home/ Take a break/ Close the office door/ None /Other	Kaarlela-Tuomaala et al., 2009
Presence of acoustic treatment	Q8	Are there any design strategies in your office aimed at the reduction of noise resulting from people chatting (sound absorption on ceiling or walls, partitions between desks, carpet, ecc.)?	Yes/No		
	Q9	If yes, what are the main strategies that are applied? (sound absorption on ceiling or walls, partitions between desks, carpets, ecc.)?	Multiple choice	Sound absorption on ceiling/ Sound absorption on walls/ Sound absorption on ceiling and walls/ Partitions between desks/ Carpets/ None /Other	
Occupants' behavior (with reference to a warning system with lighting feedback)	Q10	Would you pay attention to a light-system that advises you and your colleagues to control your voice volume in order to reduce noise resulting from people chatting in your workplace?	Yes/No		

1.3.3 Statistical Analysis

Several statistical analyses were carried out with the purpose of addressing the research questions mentioned at the beginning of Section 1.3 using MATLAB 2017 (MA, MathWorks, Natick, MA) and SPSS software (SP, IBM Statistics 20, IBM, Armonk, NY, USA). The distributions of the data samples were checked to verify the assumption of normality using the Shapiro–Wilk test (Field, 2000). The statistical tests and data analysis are summarised hereafter.

Data Analysis A1

Goal: to investigate the significance of the differences between shared and open-plan offices related to several factors, such as noise annoyance, mental health and well-being, work productivity and occupants' behaviour.

Procedure: the responses were divided into two groups according to the type of office. A non-parametric test, the Mann-Whitney U (MWU) test, was used considering the two groups of independent observations (Sigal, 1988) when the data were measured with an ordinal scale through the Likert scale ranking treated as an interval scale. Cramer's V test was used to measure the strength of the association between the categorical variables, i.e. between the type of office and noise annoyance, mental health and well-being, and work productivity (Field, 2009; Rea and Parker, 2014). In the case of data measured with a nominal scale, such as for Q2 and Q7, the *z*-test for proportions was applied (Fleiss, 2003) and the magnitude of the difference between the two proportions was calculated according to Cohen's h test (Cohen, 2013).

Spearman's correlation coefficient (r_s) was also calculated for each office type in view of the double objective: 1) to explain the correlation between noise annoyance and work productivity, mental health and well-being; 2) to verify the correlation between the responses related to perceived interruptions due to ISN (Q3) and the other responses related to work productivity (Q4 and Q5). A correlation coefficient is commonly used to measure the size of an effect (Field, 2009).

Data Analysis A2

Goal: to investigate separately how noise annoyance varied as a result of personal factors (i.e. age, gender and professional sector) and the office characteristics (i.e. city, number of people in the office and room acoustic design) in shared and open-plan offices.

Procedure: the responses were divided into two groups according to the types of office. The Kruskal-Wallis (KW) test, which is an extension of the MWU test for more than two groups, was applied in order to investigate how noise annoyance is related to different age ranges, professional sectors and to the number of people in an office. Subsequently, when a significant difference was found between groups, the MWU test was applied between paired groups, as well as for the data analysis in which there were only two-level factors (i.e. gender and location of the city).

Data Analysis A3

Goal: to investigate how noise annoyance was affected by personal and office characteristics in both shared and open-plan offices.

Procedure: A logistic regression analysis was performed. The “noise annoyance” response variable was dichotomised into “no annoyance” (1 = not at all; 2 = slightly) and “annoyance” (3 = fairly; 4 = highly; 5 = extremely). Significant covariates were identified in the models on the basis of the “forward” variable selection procedure (Bursac et al., 2008). The odds ratio, reported as the results of statistical analysis, is the most commonly used and useful measure of the effect of size for categorical data (Field, 2009).

1.3.4 Results

Descriptive statistics are presented in the following sections to offer an instant picture of the distribution of the data. In addition to the mean values, which is the most popular and well known measure of central tendency, mode values are also reported since they are commonly used for categorical data with the aim of knowing which score is most frequently selected by the employees (Field, 2009).

1.3.4.1 Effects of ISN on annoyance, productivity, mental health and well-being

The results of data analysis A1 are reported in Table 3. The lower mean and mode values of Q1 to Q6 evaluated in sample (S) are compared against sample (O), and the significant differences between the two office types, according to the MWU test ($p < 0.001$), are highlighted. The magnitude of association between the two office types is moderate for noise annoyance (V = 0.25) and work productivity in terms of interruptions (V = 0.20), according to Cramers V[1] test. Given the high significance value ($p < 0.001$), these statistics are unlikely to have such values by chance, and the strength of the relationships is therefore significant (Field, 2009). Significant positive correlations (rs ≥ 0.5, $p < 0.01$) were found between the Q3 scores related to the perceived interruptions due to ISN and the Q4 and Q5 scores in both shared and open-plan offices. These findings indicate that the employees in shared offices perceive ISN as less annoying than the employees in open-plan offices, and ISN compromises work performance less in shared offices than in open-plan offices. Conversely, the magnitude of association between the two office types was found to be weak in terms of mental health and well-being (V = 0.13, $p < 0.001$), which means that interpersonal relationships between colleagues are affected less by the type of office than by the other variables. Significant positive correlations (rs ≥ 0.5, $p < 0.01$) were found between the noise annoyance scores of Q1 and the scores of Q3 to Q6 in both shared and open-plan offices.

Table 3. Mean (Mn) and mode (Mo) values of the answers on noise annoyance, work productivity, and mental health and well-being related to ISN, for shared and open-plan offices, respectively, and two-tailed *p*-values of the significance of the differences between the two office types, according to the MWU test. Any statistically significant differences, with a *p*-value < 0.001, are reported in bold and Cramer's V values are also indicated.

Topic		Shared Offices (N = 597)		Open-Plan Offices (N = 481)		MWU *p*-value	Cramer's V
	ID	Mn	Mo	Mn	Mo		
Noise annoyance	Q1	2.54	2.00	3.07	3.00	**< 0.001**	0.25
Work productivity	Q3	3.06	3.00	3.44	4.00	**< 0.001**	0.20
	Q4	3.05	3.00	3.40	4.00	**< 0.001**	0.17
	Q5	2.98	3.00	3.22	4.00	**< 0.001**	0.14
Mental health and well-being (interpersonal relationships)	Q6	2.71	2.00	2.98	3.00	**< 0.001**	0.13

1.3.4.2 Effects of ISN on mental health and well-being, and on occupants' behaviour

The percentages of the feelings and symptoms indicated by the employees as a consequence of ISN, in shared and open-plan offices, are shown in Figure 1(a). A loss of concentration is the main feeling as a result of ISN in shared and open-plan offices, as indicated by 69% and 66% of the employees, respectively. Lower percentages were obtained for the other feelings and symptoms, i.e. 4% and 6% of the employees self-estimated mental illness, such as stress, while 6% and 9% of the them reported emotional and social feelings, such as feeling displeased, less motivated, angry and negative feelings towards colleagues, in office types S and O, respectively. Similarly, 4% and 9% of the employees related ISN with physical symptoms, such as tiredness, overstrain and headaches, in shared and open-plan offices, respectively.

The significant differences were found between shared and open-plan offices for emotional and social feelings and physical symptoms ($p < 0.05$), according to data analysis A1 for nominal scale. The magnitude of the difference between the two types of office was moderate for physical symptoms ($z = 3.63$, $h = 0.45$), while a small effect size was found for emotional and social feelings ($z = 3.63$, $h = 0.12$), according to Cohen's h[1] test. Conversely, no significant difference between the two offices was found for a loss of concentration. This result might seem counterintuitive, since work productivity is significantly less compromised in shared offices than in open-plan offices, as previously indicated in Table 3. However, it is well known that work performance is affected by several factors, such as the time of the exposure to noise, the type of task, intelligibility of the

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[1] The size effects for the *z*-test for proportions were interpreted considering Cohen's h labels (Cohen, 2013) of small (0.20), medium (0.50) and large (0.80) effects.

speech, satisfaction with the working environment and personal feelings. Given these premises, mental illness, physical symptoms, emotional and social feeling related to ISN can generally contribute to the differences in perceived work productivity between shared and open-plan offices, as can other factors that were not investigated in the present study. Moreover, employees self-reported a higher number of interruptions by colleagues in open-plan offices (Table 3), and these interruptions could therefore result in a more frequent direct loss of concentration. In other words, a loss of concentration is the main consequence of ISN in both office types, although employees could experience this symptom with different frequencies during the working hours and their productively could therefore be impaired differently.

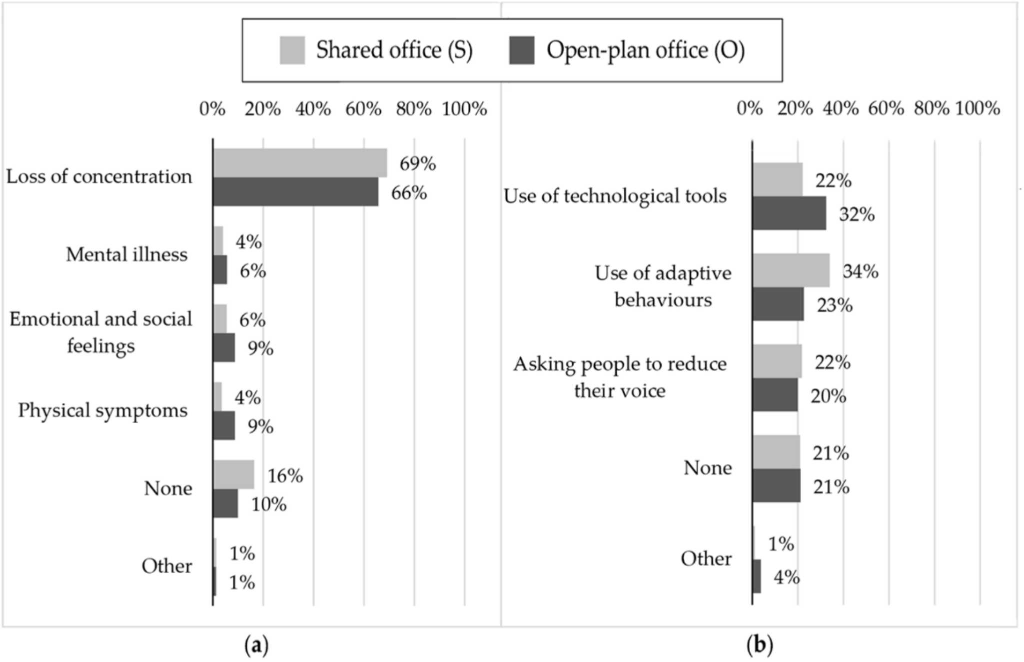

Figure 1. Percentages related to the effects of ISN on mental health and well-being, and on the occupants' behaviour in shared (S) and open-plan (O) offices: (a) Subjective ratings on feelings and symptoms attributed by the occupants to ISN; (b) Subjective ratings on personal strategies used by the occupants to cope with ISN.

Figure 1(b) shows the percentages related to different strategies adopted by the employees to cope with ISN in shared and open-plan offices, respectively. The use of technological tools, such as headphones with music and noise cancelling headphones, was the main solution for 22% and 32% of the employees in the S and O office types, respectively. Total percentages of 34% and 23% of the employees declared they adopted adaptive behaviour, i.e. taking a break, changing working space or work task, working from home and closing the office door, to cope with ISN in S and O, respectively. Furthermore, 22% and 20% of the employees preferred to ask their colleagues to reduce their voice levels in office types S and O, respectively. Significant differences were found between shared and open-plan offices, according to the z-test for proportions regarding technological tools and adaptive behaviour used by employees to cope with ISN ($z = 3.81$, $h = 0.25$ and $z = -4.08$, $h = 0.23$, respectively; $p < 0.05$). However, the magnitude of the differences between the two office types is small for both personal strategies, according to Cohen's h^2 test.

As far as Q10 is concerned, the use of a lighting feedback to lower voice levels and monitor the ISN was self-estimated as a useful strategy by 62% and 72% of the employees in shared and open-plan offices, respectively, as shown in Figure 2. Such a difference between offices was found to be statistically significant ($p < 0.05$), but the magnitude of the difference between the two types of office was found to be small after an estimation of the effect size ($z = 3.37$, $h = 0.31$).

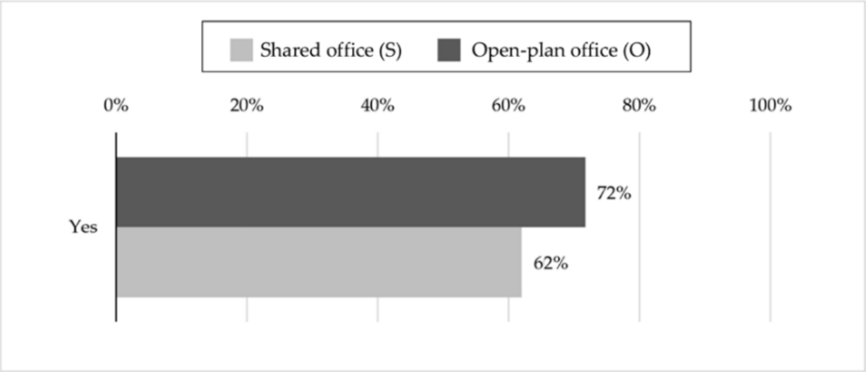

Figure 2. Percentages related to the willingness of the occupants to be influenced by a noise monitoring system with lighting feedback that encourages behavioural changes, such as a decrease of their voice volumes in order to reduce ISN.

1.3.4.3 Noise annoyance related to personal and office characteristics

Gender, age range, professional sectors and city

This and the following sections report the results of data analysis A2 and A3. Table 4 shows the mean and mode values of the noise annoyance scores divided according to gender, age range, professional sector and city location, for both types of offices, together with the significance of the differences between groups, according to the MWU or KW test.

The A2 data analyses yielded no significant difference between genders in the shared offices, according to the MWU test (U = 42065, $p > 0.05$). The same mode value (Mo = 2.00) that was obtained for both genders supports this trend. Conversely, a significant difference was found in open-plan offices (U = 118473.5, $p < 0.05$), where women appeared to be more annoyed by ISN (Mo = 3.00) than men (Mo = 2.00).

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[2] The size effects of the z-test for the proportions were interpreted according to Cohen's h labels (Cohen, 2013) of small (0.20), medium (0.50) and large (0.80) effects.

Significant differences were observed for the three age ranges, that is, 18–25, 26–35 and 51–65+ in open-plan offices, according to the KW test. A significant difference was observed between the first and the last age ranges, according to the MWU test (U = 15395, $p < 0.01$). This result means that older employees are more annoyed by ISN, as confirmed by the higher mean values (Mn = 3.21).

Table 4. Mean (Mn) and mode (Mo) values of the answers on noise annoyance related to gender, age range, professional sector and city latitude, for shared (S) and open-plan (O) offices, and two-tailed *p*-values of significance of the differences according to the MWU or KW test. Statistically significant differences are reported in bold.

	Sample	**Descriptive Statistics**	**S (N = 597)**	**O (N = 481)**
Gender	Female	Mn	2.51	3.19
	N(S) = 269, N(O) = 188	Mo	2.00	3.00
	Male	Mn	2.58	2.99
	N(S) = 328, N(O) = 293	Mo	2.00	2.00
		MWU *p*-value	0.30	**0.04**
Age range	18–35	Mn	2.36	2.92
	N(S) = 193, N(O) = 208	Mo	2.00	3.00
	36–50	Mn	2.62	3.12
	N(S) = 187, N(O) = 98	Mo	2.00	3.00
	51–65+	Mn	2.65	3.21
	N(S) = 217, N(O) = 175	Mo	3.00	3.00
		KW *p*-value	0.08	**0.03**
Professional[3] **sector**	TEC	Mn	2.62	3.18
	N(S) = 118, N(O) = 104	Mo	3.00	3.00
	EN-TE	Mn	2.38	2.90
	N(S) = 181, N(O) = 126	Mo	2.00	2.00
	MA-AD	Mn	2.60	3.10
	N(S) = 194, N(O) = 176	Mo	2.00	3.00
	CR-DE-AR	Mn	2.57	2.93
	N(S) = 46, N(O) = 30	Mo	3.00	3.00
	SPA	Mn	3.00	3.30
	N(S) = 9, N(O) = 20	Mo	2.00 and 4.00	3.00
	OT	Mn	2.65	3.16
	N(S) = 49, N(O) = 25	Mo	2.00	3.00
		KW *p*-value	0.18	0.28
City location[4]	North	Mn	2.46	3.02
	N(S) = 480, N(O) = 416	Mo	2.00	3.00
	South	Mn	2.90	3.77
	N(S) = 115, N(O) = 65	Mo	3.00	3.00
		MWU *p*-value	**<0.001**	**0.01**

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[3] The following abbreviations are used for the professional sectors: TEC for "Technical", EN-TE for "Engineering and Teaching", MA-AD for "Management and Administration", CR-DE-AR for "Creative, design and architecture", SPA for "Sales and public affairs", and OT for "Other".

[4] The northern cities are Milan, Turin and Cuneo, and southern cities are Rome and Naples.

No significant differences between professional sectors emerged for the shared offices and the open-plan offices, according to the KW test. However, the highest and lowest mean values were found for the employees that work in the sales and public affairs sector (SPA) and in the engineering and teaching sector (EN-TE), in both types of office. However, the low number of subjects involved in the public affairs sector affected the statistical results pertaining to this sector, and further investigations are required to clarify this aspect.

The cities were divided into two groups according to their location: the North and the South of Italy. Significant differences were observed between the northern and southern city locations in shared offices ($U = 20981.5$, $p < 0.001$) and in open-plan offices ($U = 11028.5$, $p < 0.05$). The mean values are higher for the subjects who work in southern cities than the mean values obtained for the office occupants in northern cities.

Number of people in the office

Significant differences emerged for the shared (S), medium open-plan (MO) and large open-plan (LO) offices from the KW test, as shown in Table 5, and significant differences between each paired office type were also found for the MWU test ($p < 0.001$). The increase in the mean values ($\Delta = 1.71$) shows that employees are more annoyed by ISN as the number of people in an office increases.

Table 5. Mean (Mn) and mode (Mo) values of the answers on noise annoyance related to the office size, and two-tailed *p*-values of significance of the difference between the number of people in offices, according to the KW test. Any statistically significant differences with *p*-values < 0.001 are reported in bold.

Descriptive Statistics	**Number of People in the Office**[5] **S (2–5)** **N = 597**	 **MO (6–20)** **N = 467**	 **LO (21–200)** **N = 14**	**KW** ***p*-value**
Mn	2.54	3.05	3.71	**<0.001**
Mo	2.00	3.00	3.00	

Presence of acoustic treatments

The subjects were asked to indicate whether their offices had undergone acoustic treatments on the basis of a personal visual inspection.

As shown in Figure 3(a), 7% and 20% of the shared and open-plan offices were acoustically treated, according to the respondents. Setting screens between

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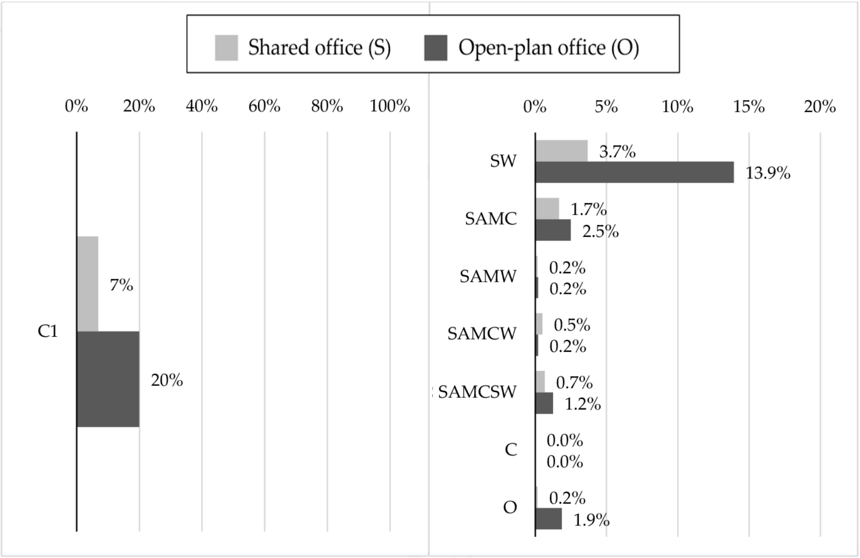
[5] The following abbreviations were used to indicate the type of office, on the basis of the number of people: S for “Shared office for 2 to 5 people”, MO for “Medium Open-plan office for 6 to 20 people”, LO for “Large Open-plan office for 21 to 200 people”.

workstations (SW) constitute the most commonly adopted acoustic treatment, and this is followed by the application of sound absorption materials to the ceiling (SAMC), as can be observed in Figure 3(b).

As shown in Table 6, significant differences emerged between the noise annoyance scores for the employees who self-estimated the presence (C1) or absence (C2) of acoustic treatments in open-plan offices, according to the MWU test (U = 14943.5, $p < 0.05$). The mean (Mn = 3.12) and mode (Mo = 3.00) values in fact indicate that employees were more annoyed by ISN when open-plan offices were not acoustically treated.



(a) (b)

Figure 3. (a) Percentages of acoustic treatments as self-estimated by the employees of shared and open-plan offices: (a) Subjective ratings on the presence (C1) of acoustic treatments; (b) Subjective ratings on the acoustic treatment types[6].

Table 6. Mean (Mn) and mode (Mo) values of the answers pertaining to noise annoyance related to the self-estimated presence of acoustic treatments in shared and open-plan offices, and two-tailed *p*-values of significance of the difference between the presence and absence of a treatment, according to the MWU test, for both types of offices. Any statistically significant differences, with *p*-values < 0.05, are reported in bold.

Sample	**Descriptive Statistics**	**Presence of Acoustic Treatment**		**MWU *p*-value**
		Yes	**No**	
		N = 41	**N = 556**	
Shared Offices	Mn	2.64	2.54	0.30
	Mo	3.00	2.00	
		N = 96	**N = 385**	
Open-Plan Offices	Mn	2.86	3.12	**0.02**
	Mo	2.00	3.00	

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[6] The following abbreviations were adopted: SW for “screens between workstations”, SAMC for “sound absorption materials on ceiling”, SAMW for “sound absorption materials on walls”, SAMCW for “sound absorption materials on ceiling and walls”, C for “carpets”, SAMCSW for “sound absorption materials on ceiling with screens between workstations” and O for “other”.

Personal and office characteristics that affect noise annoyance

A binary logistic regression was applied to investigate the relationship between the noise annoyance caused by ISN in both types of office and the covariates related to personal and office features. The reference categories in Table 7 are the ones with the lowest mean noise annoyance score shown in Tables 4, 5 and 6.

The location of the city (OR = 2.52, 95% CI: 1.65–3.89) and the acoustic treatment (OR = 2.17, 95% CI: 1.11–4.22) were identified in the regression model as the covariates that significantly affect noise annoyance in shared offices. Office employees in southern cities and employees with acoustically treated offices are almost twice as likely to report annoyance from ISN than employees who work in northern cities and in offices without acoustic treatments.

The regression model related to open-plan offices identified the gender (OR = 1.79, 95% CI: 1.19–2.70) and the number of people in the office (OR = 8.70, 95% CI: 1.11-68.20) as other covariates that, in addition to the location (OR = 2.26, 95% CI: 1.18–4.33) and the acoustic treatment (OR = 1.70, 95% CI: 1.06–2.72) were significant. It was found that being female and working in southern cities, without any acoustic treatment in the office, make it almost twice as likely to be annoyed by ISN than being male, working in northern cities and with acoustic treatments in the office. Furthermore, when there are more than 20 people in the office, it is about nine times more likely that the employees will be annoyed by ISN than when there are from 6 to 20 occupants.

The outcome related to the acoustic treatment condition was the opposite in the two office types, in agreement with the mean values shown in Table 6. The occupants of shared offices are less annoyed by ISN when the office is without any acoustic treatment, while the occupants of open-plan offices are less annoyed when the office has had an acoustical treatment.

Table 7. Odds Ratio (OR) and 95% confidence interval (CI) of the covariates that significantly (*p*-values < 0.05) affect noise annoyance in shared and open-plan offices according to the logistic regression analysis.

Covariates (reference category)	**Shared Offices (N = 597)**			**Open-Plan Offices (N = 481)**		
	OR	**95% CI**	***p*-value**	**OR**	**95% CI**	***p*-value**
Gender (Male)	-	-	-	1.79	1.19–2.70	**<0.05**
City location (North)	2.52	1.65–3.86	**0.00**	2.26	1.18–4.33	**0.01**
Acoustic treatment (Absence in shared offices and Presence in open-plan offices)	2.17	1.11–4.22	**0.02**	1.70	1.06–2.72	**0.03**
Number of people in the office (6–20)	-	-	-	8.70	1.11–68.20	**0.04**

1.3.5 Discussion

The investigation presented in this section has shown the effects of ISN on shared offices (2–5 occupants) and open-plan offices (+5 occupants), on the basis of data collected through a survey administrated in eleven small and eight large companies, five research centres and one university in Italy.

Many surveys have been carried out on noise annoyance and acoustic comfort in open-plan offices, but this aim of this study has been to provide new knowledge on the self-estimated impact of a specific noise source (ISN) on a combination of factors, that is, annoyance, performance, mental health, well-being and occupants' behaviour with respect to two office types. The associations between the perceived noise annoyance and personal characteristics (i.e. age, gender and professional sector), as well as the office features (i.e. city, number of people and room acoustic design), have also been evaluated. Moreover, the study has been aimed at evaluating the willingness of employees to reduce ISN through proactive behaviour, such as lowering one's voice, whenever a noise monitoring system with lighting feedback indicates high noise levels in the office.

Effects of ISN on noise annoyance, productivity, mental health and well-being

In the present study, ISN generated by conversations between colleagues, telephone calls and laughter has been found to be more annoying in open-plan offices than in shared ones. Moreover, an increase in noise annoyance has been self-estimated by employees according to the office size, i.e. shared, medium and large open-plan offices. Danielsson, (2005) disclosed the same findings, and found that noise due to conversation, equipment and other office noises was more annoying in open-plan offices than in smaller ones.

The perceived decrease in work productivity as a result of ISN was found to be higher in open-plan offices than in shared offices. In particular, employees declared they were often interrupted by ISN and, as a consequence, they were not able to maximise their performance in larger offices. Although the comparison between shared and open-plan offices was not specifically investigated in previous studies, this result is coherent with those of Kaarlela-Tuomaala et al. (2009). They showed that the self-estimated waste of working time, due to noise, doubled when employees moved from private to open-plan offices. An implication that can arise from the present study, in terms of office layout, is that shared offices may be considered as an alternative to open-plan offices when work productivity has to be increased.

About 70% of the employees in both types of office declared difficulties in concentrating as the main self-estimated problem caused by ISN, with no significant difference between the types of offices. This result might seem counterintuitive, since work productivity is significantly less compromised in shared offices than in open-plan offices, as indicated in Table 3. However, physical symptoms and feelings related to mental health and well-being can make a general contribution to the differences in perceived work productivity between the two offices, although they were generally stated less frequently by the employees as the main consequences of ISN. Indeed, a significant increase in physical symptoms was found in open-plan offices compared to shared ones. Moreover, other factors, which have not been investigated in this study, could contribute towards the difference in perceived work productivity between the two offices, such as the time of exposure to noise (Jahncke et al., 2011), the type of task (Perrin Jegen and Chevret, 2017), the intelligibility of speech (Hongisto, 2005) and satisfaction with the working environment (Judge et al., 2001). Although a loss in concentration is the main consequence of ISN in both types of office, the employees in open-plan offices declared they were often interrupted by ISN. These interruptions result in a frequent direct loss of concentration, thus their productively may be more compromised than that of employees in shared offices.

The pattern of the results is in line with previous studies, in which an association between the noise of different types of office and difficulties in concentration (Banbury and Berry, 2005; Kaarlela-Tuomaala et al., 2009; Pejtersen et al., 2006; Perrin Jegen and Chevret, 2017) was found, as well as a relationship with other feelings and symptoms related to mental health and well-being, such as tiredness and motivation (Jahncke et al., 2011), and fatigue and headaches (Kaarlela-Tuomaala et al., 2009; Pejtersen et al., 2006). Moreover, Pejtersen et al. (2006) pointed out a significant increase in the prevalence of physical symptoms, such as fatigue and headaches, as the size of the office increased

In addition, it has been found that interpersonal relationships between colleagues are not affected significantly more by ISN in open-plan offices than in shared ones. However, Brennan et al., 2002 found a lowering of satisfaction in co-worker relationships when employees moved from private to shared offices. Danielsson et al. (2015) pointed out that conflicts between colleagues can in part be attributed to differences in exposure to noise between office types.

Effects of ISN on occupants' behaviour

One finding of the present work is that employees mainly used technological tools, such as headphones with music, to cope with ISN in open-plan offices, while adaptive behaviour, (i.e. taking a break, changing the working space or work task, working from home and closing the office door) was the main strategy used in shared offices. However, this difference was not so significant, according to the estimation of the size effect. Kaarlela-Tuomaala et al. (2009) found that employees adopted more strategies to cope in open-plan offices than in private offices. Unfortunately, the magnitude of this difference was not indicated by the authors (Kaarlela-Tuomaala et al., 2009).

Another finding of this study is that about 70% of the employees in open-plan offices and about 60% in shared offices were willing to reduce ISN by adopting proactive behaviour, whenever a noise monitoring system with the lighting feedback informed them about the increase in ISN levels. This result has an important implication: the use of a noise monitoring system with lighting feedback could be an effective complementary method in shared and open-plan offices, since an accurate acoustic design of a room is not enough on its own to reduce the distraction and annoyance generated by nearby speech sounds (Haapakangas et al., 2014; Hongisto et al., 2016). In this way, positive behaviour of the occupants would be promoted, such as lowering their voice levels or changing the room in which they chat. In addition to the common passive measures introduced to reduce ISN, such as the acoustic design of a room (Haapakangas et al., 2014; Hongisto et al., 2016; Schlittmeier and Liebl, 2015; Seddigh et al., 2015) and/or sound masking (Haapakangas et al., 2011; Renz et al., 2018; Schlittmeier and Liebl, 2015), a noise monitoring system with lighting feedback may be able to reinforce and promote office etiquette, as well as a behavioural code. However, it is important to take into account an aspect of this result: the choice of the researchers to present a very general question, without any visual reference to the SEM device, may have caused possible misinterpretation of the question due to the absence of a single, well-known device with the lighting feedback for anthropic noise control.

Effects of personal and office characteristics on noise annoyance

Women were found to be significantly more annoyed than men in open-plan offices, while no differences were found for shared offices. This outcome is in line with those of (Kaarlela-Tuomaala et al., 2009) and (Danielsson et al., 2015), who found that women were more disturbed by noise than men in open-plan offices. Older employees in open-plan offices were found to be more annoyed than younger ones; a significant difference between people in the 18–35 age group and the 51–65+ age group was in fact found. In line with this finding, Pierrette et al.(2018) found that perceived annoyance due to ISN was significantly correlated to age, while (Sakellaris et al., 2016) documented that noise was an important factor for older employees in open-plan offices.

The location of the cities was another significant factor that affected the perceived annoyance due to ISN. Indeed, the results showed that employees working in southern cities were more annoyed than their counterparts working in northern ones. Noise annoyance is generally in part caused by the acoustical characteristics of the environment, and in part by the variance of personal and social variables (Guski et al., 1999). In line with this, the difference in the perceived noise annoyance in relation to the location of the cities for both office types could be caused by the multiple socio-economic-cultural variables that characterise the north-south differential, which have become consolidated over the years (Bigoni et al., 2016; Carboni and Russu, 2018; Ichino and Maggi, 1999).

According to the employees, only a small percentage of offices had been acoustically treated. Screens between workstations were identified as the most frequently adopted acoustic treatment in open-plan offices. Employees were in fact found to be significantly more annoyed by ISN when open-plan offices were not acoustically treated, while the opposite result emerged for shared offices. Seddigh et al. (2015) showed that improved room acoustics was associated with lower perceived disturbances and cognitive stress in open-plan offices; however, in order to prove this aspect in the present study, it would be necessary to conduct objective measurements of noise levels and obtain further information about the introduced acoustic treatments.

When all the above-mentioned characteristics were considered together to evaluate the most important factors that affect noise annoyance in shared and open-plan offices, some of them resulted to be more significant than others. Office location and the room acoustic design significantly affected the perception of noise annoyance in both office types, while gender and the number of people in the office were only significant factors in open-plan offices. It is important to underline that open-plan and shared offices were affected by the acoustic treatment of rooms in different ways. Noise annoyance was reduced as the result of an acoustical treatment in the former and without any acoustical treatment in the latter. In open-plan offices, where ISN levels are generally higher than in shared ones, the application of an appropriate quantity of sound-absorbing materials reduces sound energy, and consequently the ISN level decreases at the listener's ear, and this in turn results in a slight decrease in noise annoyance (Schlittmeier et al., 2008). Moreover, in the case of a good acoustic design, ISN can be less intelligible, due to a high number of people talking and masking each other, and it may therefore be less annoying (Schlittmeier and Liebl, 2015). Furthermore, a good speech level can guarantee a good level of speech privacy (Bradley, 2003). Conversely, the ISN level is generally lower in shared offices than in open-plan offices, due to the presence of fewer people, but it is also more intelligible since fewer people talk and mask each other. Furthermore, the absence of an acoustic treatment can lead to an increase in reverberation, and speech privacy consequently increases (ISO, 2017). For this reason, the occupants could have identified a more reverberant environment as less annoying, because it resulted in less intelligible speech. In order to obtain a better understanding of these aspects, future research will involve conducting the same type of investigation inside the same offices types, but with the addition of acoustic measurements in both acoustically treated and untreated offices, and with or without the presence of a light system that advises people to reduce their voice levels.

1.3.6 Limitations of the study

The present study suffers from some limitations. The comparison between the results of this work and the findings of previous studies should be interpreted with caution, since the self-assessment questionnaire was not validated according to all validity and reliability procedures indicated in the e.g., (Ortalda, 1998; Converse and Presser, 1986; Brisson et al., 1998; Taherdoost, 2018). Nevertheless, an exploration stage was performed according to (Converse and Presser, 1986): experts in acoustics and architecture and people from the target population were involved in order to identify any ambiguities in the questions and to determine the list of possible responses for the proposed alternatives. Moreover, some questions were taken from distinguished literature that used validated questionnaires. Another limitation is that additional factors, such as noise sensitivity (Schutte, 2007) personal attitudes and psychosocial factors (Guski et al., 1999) were not introduced into the used survey, even though they can affect noise annoyance.

The cross-sectional study method itself suffers from a limitation: it does not allow the causality of the identified association between ISN and several of the investigated factors to be established (Kaarlela-Tuomaala et al., 2009). Moreover, certain limitations are related to resorting to an online survey (Wright, 2017). In particular, the nonresponse bias cannot be investigated online, since the identity of non-respondents is generally unknown (Sax Linda J., Gilmartin Shannon K, 2003). There is also a self-selection bias, i.e. subjects that were more annoyed by ISN in their offices may have been more likely to complete the questionnaire than those who were not so annoyed. This bias could be particularly marked due to the low response rate. Finally, the multiple responses of subjects cannot be excluded.

1.3.7 Conclusions of the study

This cross-sectional study has compared the subjective outcomes of shared offices (2–5 employees) and open-plan offices (+5 employees) related to irrelevant speech noise. An online questionnaire was administrated in nineteen companies, five research centres and one university in Italy, thereby involving a total of 1078 subjects, of which 55% and 45% worked in shared and in open-plan offices, respectively.

Irrelevant speech noise was found to be more annoying in open-plan offices than in shared offices, and performance to be compromised more in the former than in the latter as a result of such noise. In open-plan offices, being female, and working in southern cities without any acoustic treatment in the office, made it more likely for the respondents to be annoyed by irrelevant speech noise than being male and working in the northern cities with acoustic treatments in the office. Furthermore, having more than 20 occupants in an office made being annoyed more probable than having from 6 to 20 occupants. Moreover, working in the southern cities and with acoustic treatments in the office made it more likely that noise annoyance will be reported in shared offices.

A high percentage of employees stated they were willing to reduce irrelevant speech noise if a noise monitoring system with lighting feedback advised them to reduce their voices.

1.4 External incentives to promote occupants' engagement

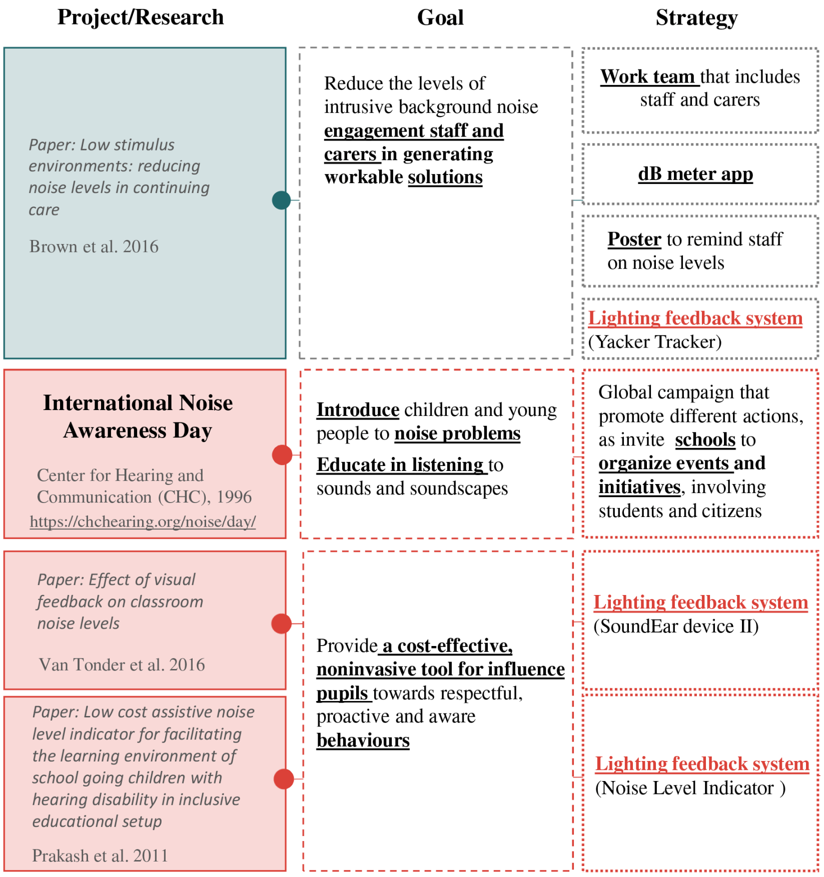
As mentioned in Section 1.1, the international research community is highly committed to promoting external incentives aimed at motivating the engagement and behavioural changes of people to cope with noise generated by occupants.

As shown in Figures 4 and 5, researchers are dedicating efforts to the application of similar strategies in both indoor and outdoor environments, including ICT-based solutions (mobile phones, websites, e-mails, room displays), subjective surveys, awareness campaigns, lighting feedback systems, paper-based and/or media communication. However, no detailed indications on the persistence of behavioural changes as a result of external incentives are yet available in the literature: most of the results related to leisure noise have been shared in international conferences, and the lack of precise results on the effects of external solutions is due to the recentness of such themes. For example, despite the greater efforts made in communicating with citizens, the goal of engagement in the reduction of leisure noise has not yet been achieved (Asensio et al., 2018).

As mentioned in Section 1.1, the awareness of the impact of behavioural changes on indoor comfort and building energy use is increasing among occupants. In line with the external incentives shown in Figures 4 and 5, European projects, developed within the Horizon 2020 programme, are aimed at achieving a behavioural change using ICT-based solutions, awareness campaigns and media communication strategies (Barthelmes et al., 2019). Some issues related to the usability of ICT solutions, such as the ineffectiveness of the provided feedback and difficulties in achieving proactive behaviour in order to reach energy saving goals, have also emerged in energy projects, thus further work is needed to better understand this complex theme (Barthelmes et al., 2019).

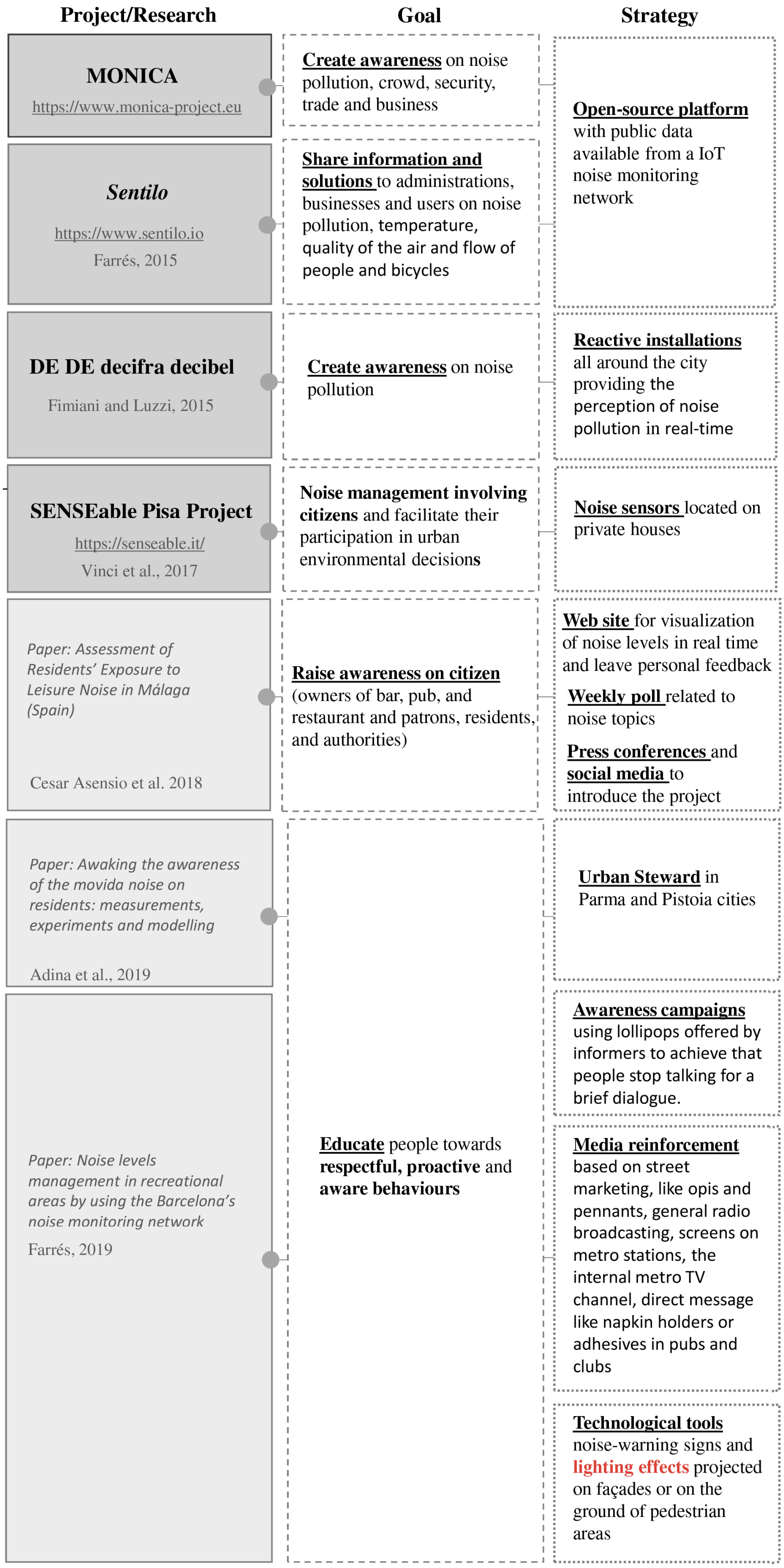
Only a few studies have investigated the use of innovative solutions to externally motivate proactive behaviour, and these have mostly been conducted in classrooms. Prakash et al. (2011) developed a lighting feedback system, called Noise Level Indicator, which was used in ten classrooms for a fortnight. This device is able to record noise levels through one or more electret microphones, the number of which depends on the size of the classrooms, and to provide lighting feedback through led lights and three bulbs (green, yellow and red) when the noise levels exceed three predetermined values. The authors did not use this system as a measurement tool; they in fact performed noise measurements prior to the installation of the devices. The average equivalent noise levels ranged from between 61 dB(A) and 81 dB(A) in occupied conditions. In a subjective investigation involving students, teachers and the management area (i.e. the deputy head teacher or head teacher's secretary), a reduction in the noise levels was perceived after the installation of the lighting feedback device, as well as an overall improvement of the learning environment. Van Tonder et al. (2016) conducted another experiment in three primary classes, that is, from first to third-grade over 36 hours of classroom activities, adopting the SoundEar II device (https://soundear.com/). The study showed that the device led to a significant decrease in the average noise levels, that is, of 68 dB(A) and 66.6 dB(A), during the baseline and intervention recording periods, without and with visual feedback, respectively. These studies show that efficient lighting feedback systems are already available on the market. SoundEar is currently developing and selling a wide range of products, as the market demand for such systems is continuously increasing. However, no scientific articles have been found on the application of visual feedback systems in open-plan offices; only some publications are available on the SoundEar web site. Nonetheless, the studies discussed so far have exhibited the following gaps and shortcomings:

- A lack of detailed indications on the effects of external incentives on behavioural changes and their fulfilment over a long-term period.
- The absence of long-term applications of lighting feedback devices in indoor environments to address the capability of this system to engage occupants and encourage proactive behaviour.



Project/Research	**Goal**	**Strategy**
Paper: Low stimulus environments: reducing noise levels in continuing care Brown et al. 2016	Reduce the levels of intrusive background noise **engagement staff and carers in generating workable solutions**	**Work team** that includes staff and carers **dB meter app** **Poster** to remind staff on noise levels **Lighting feedback system** (Yacker Tracker)
International Noise Awareness Day Center for Hearing and Communication (CHC), 1996 https://chchearing.org/noise/day/	**Introduce** children and young people to **noise problems** **Educate in listening** to sounds and soundscapes	Global campaign that promote different actions, as invite **schools** to **organize events and initiatives**, involving students and citizens
Paper: Effect of visual feedback on classroom noise levels Van Tonder et al. 2016	Provide **a cost-effective, noninvasive tool for influence pupils** towards respectful, proactive and aware **behaviours**	**Lighting feedback system** (SoundEar device II)
Paper: Low cost assistive noise level indicator for facilitating the learning environment of school going children with hearing disability in inclusive educational setup Prakash et al. 2011		**Lighting feedback system** (Noise Level Indicator)

Figure 4. Overview of external incentives applied in indoor environments to cope with noise generated by occupants. The green and red colours indicate researches in hospital and school classrooms, respectively.



Project/Research	Goal	Strategy
MONICA https://www.monica-project.eu	**Create awareness** on noise pollution, crowd, security, trade and business	**Open-source platform** with public data available from a IoT noise monitoring network
Sentilo https://www.sentilo.io Farrés, 2015	**Share information and solutions** to administrations, businesses and users on noise pollution, temperature, quality of the air and flow of people and bicycles	
DE DE decifra decibel Fimiani and Luzzi, 2015	**Create awareness** on noise pollution	**Reactive installations** all around the city providing the perception of noise pollution in real-time
SENSEable Pisa Project https://senseable.it/ Vinci et al., 2017	**Noise management involving citizens** and facilitate their participation in urban environmental decisions	**Noise sensors** located on private houses
Paper: Assessment of Residents' Exposure to Leisure Noise in Málaga (Spain) Cesar Asensio et al. 2018	**Raise awareness on citizen** (owners of bar, pub, and restaurant and patrons, residents, and authorities)	**Web site** for visualization of noise levels in real time and leave personal feedback **Weekly poll** related to noise topics **Press conferences** and **social media** to introduce the project
Paper: Awaking the awareness of the movida noise on residents: measurements, experiments and modelling Adina et al., 2019	**Educate** people towards **respectful, proactive** and **aware behaviours**	**Urban Steward** in Parma and Pistoia cities
Paper: Noise levels management in recreational areas by using the Barcelona's noise monitoring network Farrés, 2019		**Awareness campaigns** using lollipops offered by informers to achieve that people stop talking for a brief dialogue. **Media reinforcement** based on street marketing, like opis and pennants, general radio broadcasting, screens on metro stations, the internal metro TV channel, direct message like napkin holders or adhesives in pubs and clubs **Technological tools** noise-warning signs and lighting effects projected on façades or on the ground of pedestrian areas

Figure 5. Overview of external incentives applied in urban spaces to cope with leisure noise. The projects are indicated in dark grey and scientific articles are reported in light grey.

PART 2

Speech and Sound SEMaphore device

Overview

Part 1 introduced irrelevant speech noise as a main source of noise that negatively affects comfort, performance, health and well-being in densely occupied environments, especially in classrooms and open-plan offices. The development of external incentives, such as etiquette polices (Bradley, 2003; Zamani and Gum, 2019), participation in the design process (Rolfö, 2018), activity-based working (Appel-Meulenbroek et al., 2010) and visual feedback systems (Prakash et al., 2011; Van Tonder et al., 2016), can be a challenging task for motivating occupants to change their behaviours and for promoting the improvement of acoustic environments.

In the present research, a novel **noise monitoring system with lighting feedback** has been developed; it is named Speech and Sound SEMaphore device (SEM). Therefore, this chapter aims to introduce:

- The **main goals and the design of the two SEM prototypes.**
- The **key factors** that make SEM different from other devices, e.g. the adoption of **adaptive algorithms** for controlling the variation of the colours of the visual feedback.
- The **prototyping phase of the SEM Beta version** aimed to solve weaknesses of the Alpha prototype and to close as much as possible the gap between the prototype and an end-user product ready for real-life adoption.
- The outcomes of the **calibration and validation procedures** of the Beta prototype aimed to validate SEM as an accurate measurement tool.

2.1 Aims and operating principles

The interest on lighting feedback systems (described in detail in Section 1.4) has been rising in both the international research and commercial market in the last decade. However, the adoption of these systems is still limited and the knowledge on noise reduction as a consequence of proactive behaviour, such as voice lowering or room switching, is still unknown, in particular over a long-term period.

In this framework, a noise monitoring system equipped with a lighting feedback, named SEM (Speech and Sound SEMaphore) has been developed by the Applied Acoustic Group at Politecnico di Torino: an Italian patent has been granted in 2011 (Patent: 2011IT-TO00975, 27/10/2011). Figures of SEM prototypes are reported in Section 2.2. SEM has been conceived with a twofold purpose: (i) measure noise levels generated by occupants; (ii) encourage active engagement and involve occupants in improving the overall acoustic condition through more aware behaviours. A key difference of SEM against the main competitor, SoundEar, is the capability to adapt the lighting feedback based on the actual environmental conditions: the colours range from green to yellow and red, led by an adaptive algorithm which does not rely on pre-set limits of sound levels, but links the variation of Sound Pressure Level (SPL) to human perception. According to the literature, a 3 dB change is just noticeable, a 5 dB change is clearly noticeable, and a 10 dB difference is perceived as a doubling or halving of sound level (Cowan 1994). Nonetheless, the equivalent continuous sound level (L_{eq}) is not sufficient to predict annoyance caused by the fluctuations of sound levels (Robinson, 1971); therefore, the adaptive algorithm is based on the difference between statistical sound levels A-weighted (L_{Ax}) selected according to the intended use of the space. Within the present research, two versions of algorithm have been developed to best suit the installation environment: they are labelled "CL" and "OF" to recall, respectively, the algorithms optimized for classrooms and open-plan offices.

2.1.1 Algorithm CL

In classrooms, noise generated by pupils' is dominant (Shield and Dockrell, 2004), therefore sensitivity to this kind of noise is a killer requirement for the algorithm. The best measure to be monitored has been identified in the A-weighted level exceeded for 90% of a defined time unit (L_{A90}), as defined by Bottalico and Astolfi (2012), where no significant difference was found between L_{A90} and $L_{nA,hist}$. This latter measure has been used to represent the noise levels inside the classroom during teaching activities. Moreover, the A-weighted percentile level L_{A90} allows to filter instantaneous noise levels, thus enabling to avoid switching on the red light for instant events, such as door closing or objects falling.

The algorithm for data processing is based on the following steps: 1) collect and store raw samples based on A-weighted sound levels (L_{Aeq}); 2) evaluate the statistical sound levels (L_{A90}) every 5 s; 3) evaluate the difference between the last two evaluations of L_{A90}; 4) adapt the lighting feedback, based on the change in L_{A90}

and the afore-mentioned pre-set thresholds related to the relationship between the variation of SPL and human perception.

At the first step of such data processing, a reference L_{A90} value, set in the device, is used. This adaptive approach, nonetheless, would result in a green light even for high noise levels, provided that they have been achieved with small noise increases. Therefore, a further threshold is used to define an excessively high level and switch to red light, regardless of the noise increase in the last few s. This threshold is set in the range of 62-65 dB(A). A detailed flowchart of the algorithm CL is provided in Appendix A.

The main scheme of the algorithm was developed before this PhD research project; the present dissertation focused on the validation of pre-set thresholds and the definition of appropriate time intervals for switching the lighting feedback, based on objective measurements, in-field observations and subjective assessments at the beginning of each monitoring campaign. Since annoyance caused by noise levels and the occupant behaviour in response to this feeling are related to various psychological and sociological factors (Kryter, 1970), the collection of subjective evaluations of teachers and pupils was an asset to ensure appropriate variation of the lighting feedback. Indeed, the 5-s time interval has been set based on the pupils' needs to see the change of the coloured lighting feedback almost in real time, to best relate the colour change to the variation of sound levels.

2.1.2 Algorithm OF

The algorithm OF has been designed within the PhD research project and tested during a pilot study performed in a Finnish open-plan office; the results were promising, nonetheless some additional tuning is necessary according to the observations and the collected subjective opinions (described in detail in Section 3.2). Therefore, further monitoring campaigns in different open-plan offices are required to gain a clearer picture of the user interaction with SEM and to define a robust algorithm based on subjective perception and objective measurements, which are also needed to validate the choice of L_{A50} as a reference value.

The challenge associated with the algorithm OF is to make it sensitive to the sound level fluctuations proper of open-plan office environments, in which soundscape and behavioural patterns vary greatly compared with classrooms. Figure 6 shows a comparison between different L_{Ax} measures against L_{Aeq} statistical levels: the plot highlights that L_{A50} best describes the median fluctuation of SPL caused by office activities (e.g. employees' conversation, telephone rings and movements), which are considered the prevalent noise source in an open-plan office occupied by more than one person (Martellotta et al., 2011).

The algorithm for data processing is based on the following steps: 1) record sound data at 44100 kHz; 2) calculate the sound levels A-weighted ($L_{Aeq,fast}$) every 1/8 second and store the values for subsequent elaborations; 3) estimate the sound levels A-weighted ($L_{Aeq,slow}$) every 1 second; 4) evaluate the difference between

$L_{eq,slow}$ and the reference value of L_{A50}; 5) switch the corresponding lighting feedback according to the calculated difference and pre-set thresholds related to the relationship between the variation of SPL and human perception. The reference value of the A-weighted level exceeded for 50% (L_{A50}) is calculated every 5 s and it updated to evaluate the difference specified in point 4). The flowchart of the algorithm OF is not reported in this dissertation since it is under development phase.

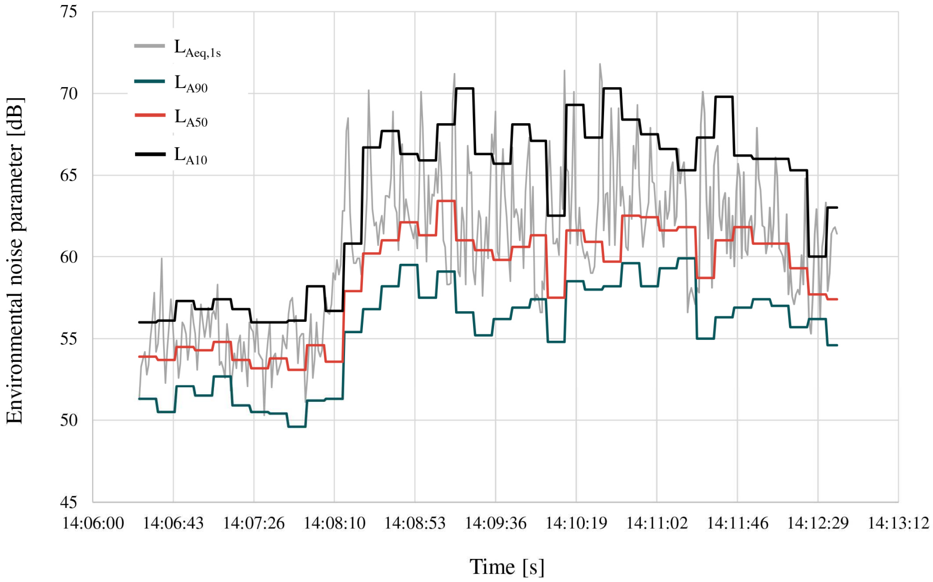


Figure 6. A-weighted noise level every 1 s ($L_{Aeq,1s}$) and A-weighted percentile levels (L_{A90}, L_{A50}, L_{A10}) related to a typical office noise. Background noise levels are only present in the first 2 minutes, afterwards people talking overlapped.

2.2 Prototyping: from Alpha to Beta prototype

Two prototype versions of SEM have been designed in order to validate the operational principles of the technology and to investigate how SEM is experienced by occupants in different real environments. Figure 7 shows the comparison between the Alpha and Beta prototypes in terms of physical structure and hardware components.

2.2.1 Alpha Prototype

The Alpha prototype has been developed within the Regional Operational Program (Piedmont – IT) FESR.2007/2013 in collaboration with ONLECO S.r.l. The study was carried out in line with the topic of the PHC-04-2015 Call for Personalising Health and Care of the Horizon 2020 notice, which is entitled "Health promotion and disease prevention: improved inter-sector co-operation for environment and health based on interventions". The Alpha prototype (Figure 7) is a totem based on a transparent panel enlightened by a coloured through-light beam. The device is equipped with a class 2 Sound Level Meter device (ISO-TECH SLM 52N) for recording of sound levels. Data are given in input to the algorithm which, in turn, provides information to a microcontroller board (Arduino Zero) that controls the lighting feedback. Further, a Wi-Fi module (miuPanel) enables to transfer data to a

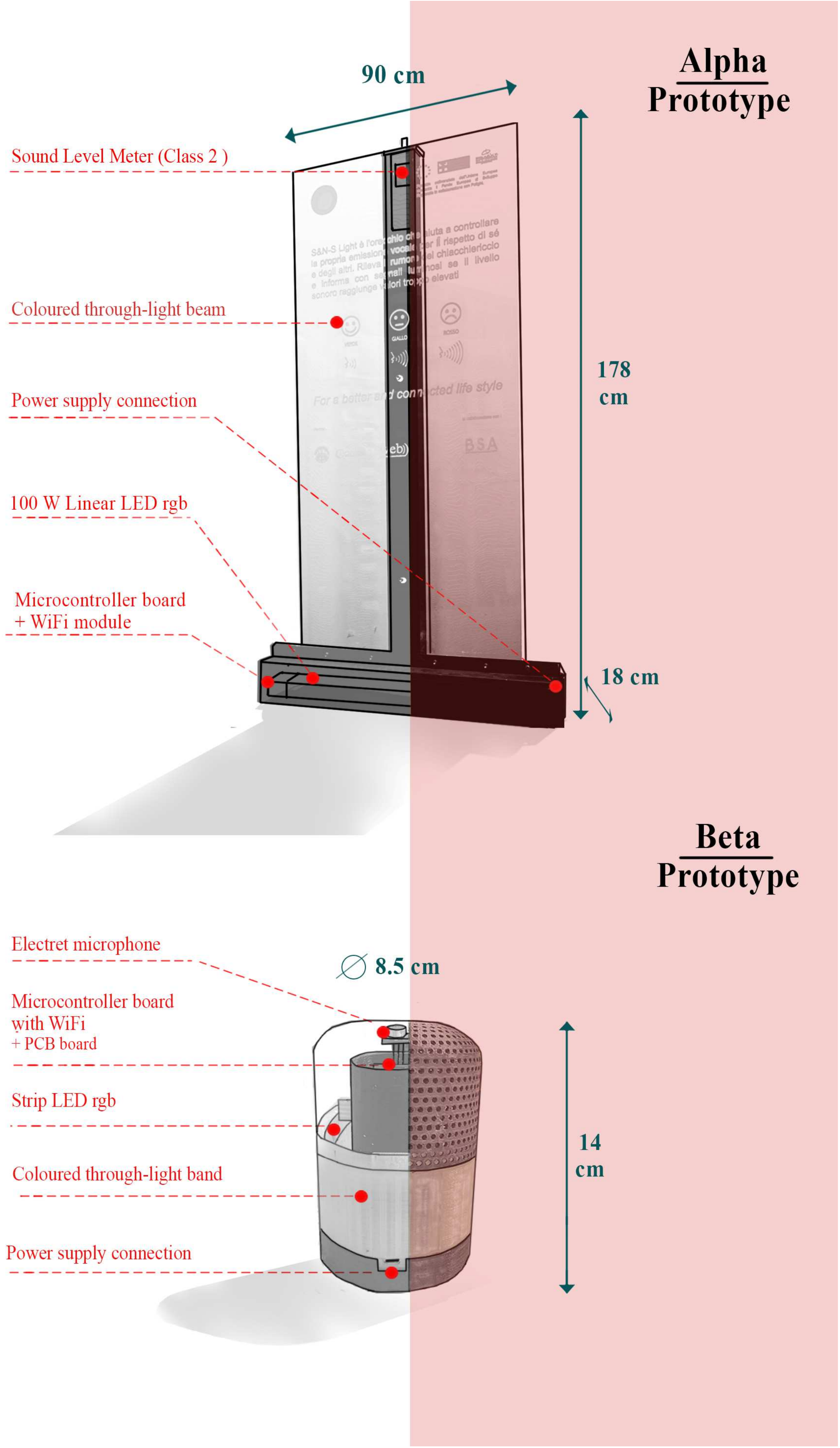


Figure 7. Diagrammatic representation of Alpha and Beta prototypes, their hardware components and physical dimensions

central server and to a customized mobile app (http://www.miupanel.com/overview/). Data transfer and data visualization systems have been developed in collaboration with the Department of Electronics and Telecommunications of Politecnico di Torino. The Alpha prototype has been applied in the monitoring campaigns in primary school classrooms where the algorithm CL was used (described in detail in Section 2.1.1). Several weaknesses emerged during the validation of this prototype in school classrooms within the PhD research project. It was found that the size of the device could hinder its adoption, as an area with an appropriate size – including clearance for manoeuvrability – is necessary. Further, core components were expensive, and flexibility and adaptability to different environments were poor caused by physical structure. For example, the lighting feedback was not clearly visible in spaces where occupants are not arranged in row, such as in classrooms. These weaknesses could seriously jeopardize the large-scale deployment of SEM, therefore a Beta prototype has been developed within the present PhD research project, with the clear purpose of designing a low-cost and scalable noise monitoring system for its adaptation in large-scale application.

2.2.2 Beta Prototype

The prototyping activities have covered a great part of the PhD research activities, including the selection and purchase of the hardware components, the development of the algorithm OF and its code, and the design of the case, as well as the validation and calibration procedures. A multidisciplinary approach was used in the design process of Beta prototype involving the laboratory technicians, ONLECO S.r.l., Bottega Studio Architetti and Department of Electronics and Telecommunications of Politecnico di Torino, therefore the management of the entire process and the multidisciplinary group was a core activity of the PhD research project. Manufacturing and assembly of 15 prototypes have been carried out by an external company. The Beta prototype (Figure 7) consists of a small table device with a through-light band, a low-cost electret condenser microphone (ECM, model MAX4466 by Adafruit Industries, NYC) and a microcontroller board (NanoPi Duo 512 Mb), which wirelessly transfers data to a central server.

This prototype could be considered as "T" prototype because the plastic casing is realized at a temporary level using additive manufacturing, while the hardware and software parts are developed in depth. Thus, Beta prototype combines the advantages of the horizontal and vertical prototypes (Rex and S, 2012). According to Nielson concept (Nielsen, 1993), the first one indicates a prototype that includes all characteristics without deepening of its functionality, conversely the vertical prototype shows only a narrow breadth of features, each of them being built in depth. In other words, the Beta prototype has been developed in order to be representative of a product ready to enter the productization for large-scale application.

In particular, the engineered electrical components have been designed to exhibit enhanced signal processing capabilities and to promote a possible, future mass production, thus a time- and cost-efficient manufacturing and assembly process. In addition, a web page (Figure 8) has been developed with a threefold purpose: 1) enable the device owners (here, the researchers) to remotely download data and monitor the status of the prototypes; 2) visualization by users of real-time noise levels; 3) visualization of historical trends with an intuitive representation based on the percentage of green, yellow and red colours obtained and the overall background noise levels. Therefore, the web page aims to raise the awareness among occupants on the impact of their behaviour on the background noise levels and, consequently, on the acoustic quality. In further developments, statistical noise report or gamification strategies could be implemented in the web page for motivating users' engagement. The entire independence between casing and hardware/software components is an asset to plan a flexible and customizable product design, based on the intended use and customers' needs. Finally, the small size and the lightness of the Beta prototype ensure an easy portability encouraging the large-scale adoption in real environments or the on-the-fly repositioning based on actual needs. The attributes and the related requirements needed to design the scalable, accurate and adaptable prototype are summarized in Table 8.

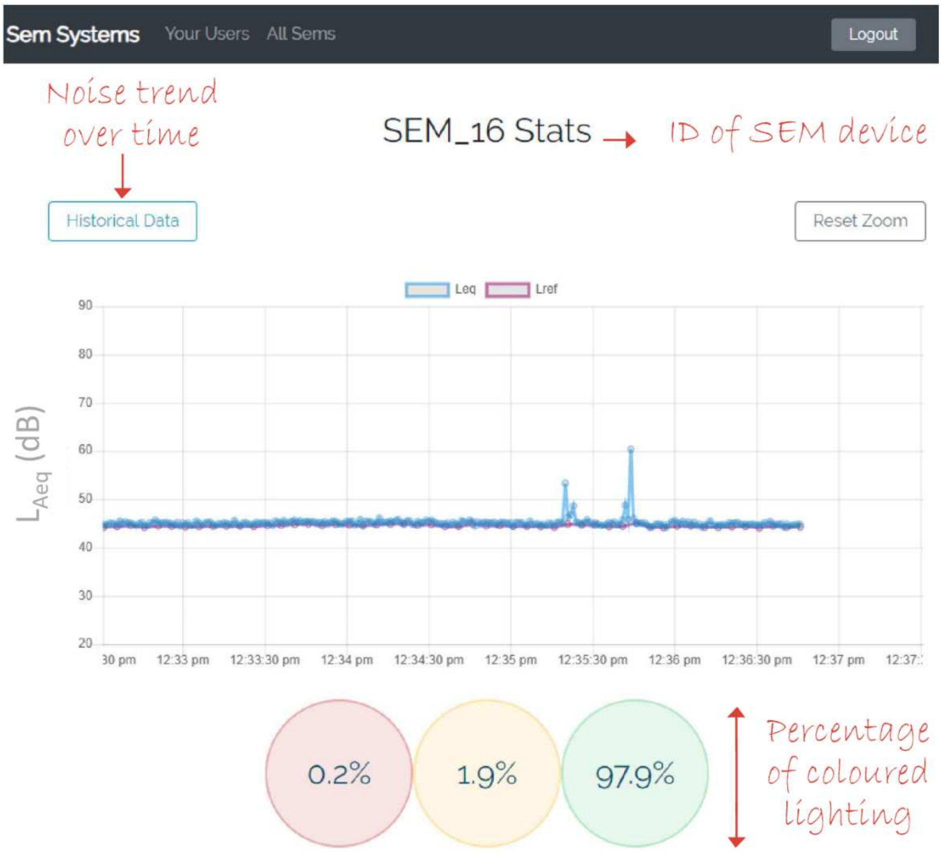


Figure 8. Example of web page. Real-time visualization of the sound levels A-weighted, the percentages of green, yellow and red colours obtained by SEM device selected by users through a previous page. Historical data can be visualized selecting the button in the upper part of the page.

Table 8. Summary of the attributes and the related requirements of the Beta prototype.

Attribute	Requirement
Portability	Small size and lightness
Cost-efficiency	Low-cost electronic components (less than 100 euro per prototype as of 2018)
Time-efficiency	Short assembling and manufacturing time
Versatility	Hardware/Software and casing totally independent
Visibility	Customizable device depending on the intended use of environment
Enhanced capabilities for signal processing	Customized printed circuit board (PCB) and programmed software system

2.3 Calibration and validation of the Beta prototype

The aim of this section is twofold: 1) describe the calibration by comparison procedure performed in order to make SEM prototypes able to measure reliable Sound Pressure Level (SPL) according to a class 1 Sound Level Meter (SLM), and 2) explain the results of field validation in order to proof whether SEM prototypes are able to provide accurate sound measurements. The calibration and validation procedures were performed using the whole SEM prototype: the perforated outer cap was maintained for the calibration procedure in order to evaluate its possible influence on the frequency response of SEM prototypes.

Further acoustic tests prescribed by 2013 IEC specification, such as self-generating noise and long-term stability, will be performed when the prototype will be in a more advanced stage of production. According to the Technology Readiness Level (TRL) scale, originally defined by NASA for measuring or indicating the maturity of a given technology (ISO 16290:2013), further acoustic testing and third-party certification will be needed to switch from TRL 7, that indicates the prototype demonstration in operational environment, to TRL 8 where complete and qualified system is required.

2.3.1 Calibration by comparison

In collaboration with Department of Electronics and Telecommunications of Politecnico di Torino (PoliTo), the calibration procedure has been performed in the anechoic chamber of PoliTo, where the A-weighted equivalent background noise level ranged between 25 and 26 dB (Castellana, 2018; Castellana et al., 2017). SEM prototype with the Electret Condenser Microphone amplifier that has an operating frequency range from 20 Hz to 20 KHz (ECM, model MAX4466 by Adafruit Industries, NYC) and a class 1 Sound Level Meter with the reference omnidirectional microphone (SLM, model XL2 by NTi Audio, Schaan, Lietchtenstein) were placed in front of the directional acoustic source (NTi Audio

TalkBox, Schaan, Liechtenstein). This latter was set to generate at 75 dB white noise in the frequency range from 0.1 to 10 kHz at a distance of 55 cm from the measurement tools and 1.5 m from the floor (Figure 9).

The phases of calibration procedure are reported as follows:

1. Perform a frequency response comparison between the SLM and SEM prototype.
2. Define a filter based on frequency response compensation (FRC), that is shown in Figure 10.
3. Make a Global Correction Filter (GCF) able to take into account the FRC, the frequency A-weighting filter (IEC 60812, 2006) and the offset adjustment estimated for each prototype by the calibration signal of a 1 kHz sine wave at 94 dB(A).

Figure 9. Set-up of the calibration by comparison in the anechoic chamber of PoliTo.

The block diagram of SEM prototype functionality is shown in Figure 11.

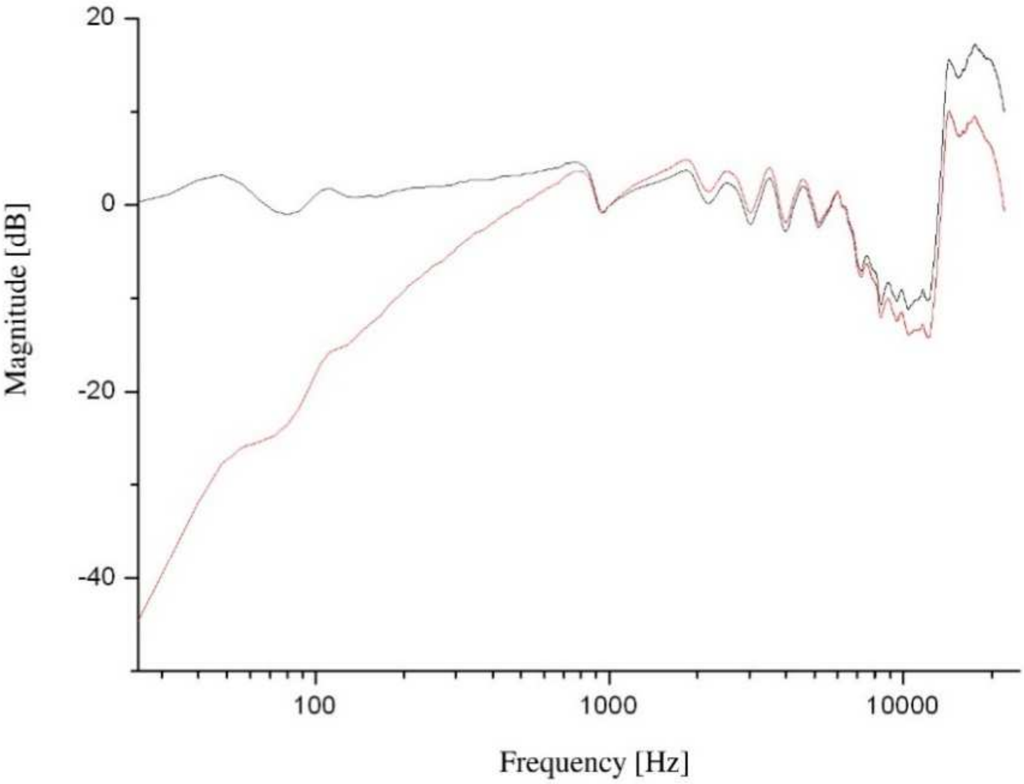


Figure 10. Frequency response compensation filter (FRC). The black line indicates the FRC without A-weighting filter, while the red line represents the FRC A-weighting filter.

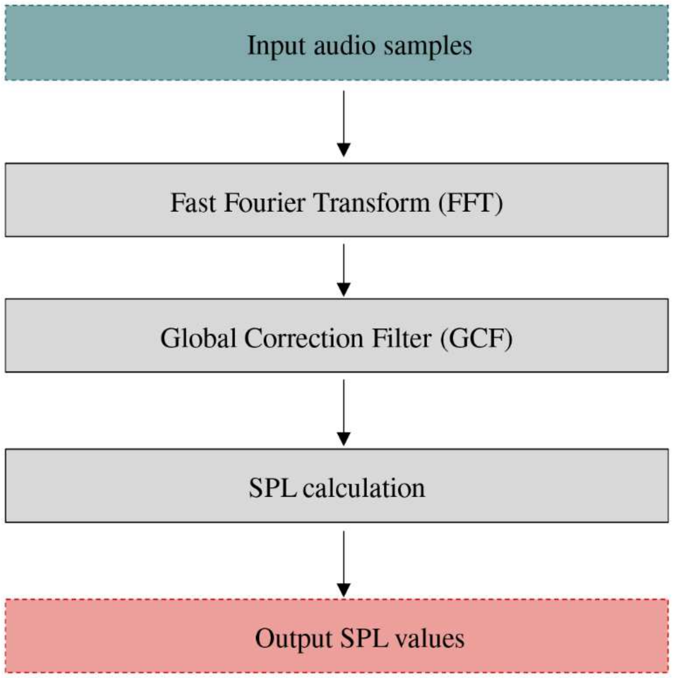


Figure 11. Block diagram of signal processing related to the Beta prototype.

2.3.2 In-field validation

A measurement in a shared office at Politecnico di Torino has been performed in order to validate the Global Correction Filter (GCF) resulting from the calibration by comparison and, consequently, to evaluate the accuracy of SEM prototype to measure reliable decibel levels for different frequency ranges in real environments.

The SEM prototype and the class 1 Sound Level Meter (it is the same used in the calibration procedure) were placed at a distance of 1.2 m from the floor and at the centre of the room (7 m × 3 m) during a typical working day. The shared office was occupied by a total number of 4 people that performed 1-min intervals of free speech, and the background sources, such as HVAC system and human activities in other offices and corridor, were present. Overall, the measurement session lasted for about 1 hour.

Figure 12 shows the average frequency response, obtained as a mean among all the acquisitions, for SEM prototype and Sound Level Meter, respectively. Similar SPL trends over frequency are found, with a maximum difference of about 2 dB in 400 and 630 Hz. A higher difference was found in the low frequency range (63 – 200 Hz), which is out from the typical speech spectrum, that ranges between 125 and 2000 Hz. Provided the main purpose of this device, that is control noise generated by human speech, these results show that SEM prototype is able to measure reliable decibel levels in the proper frequency range.

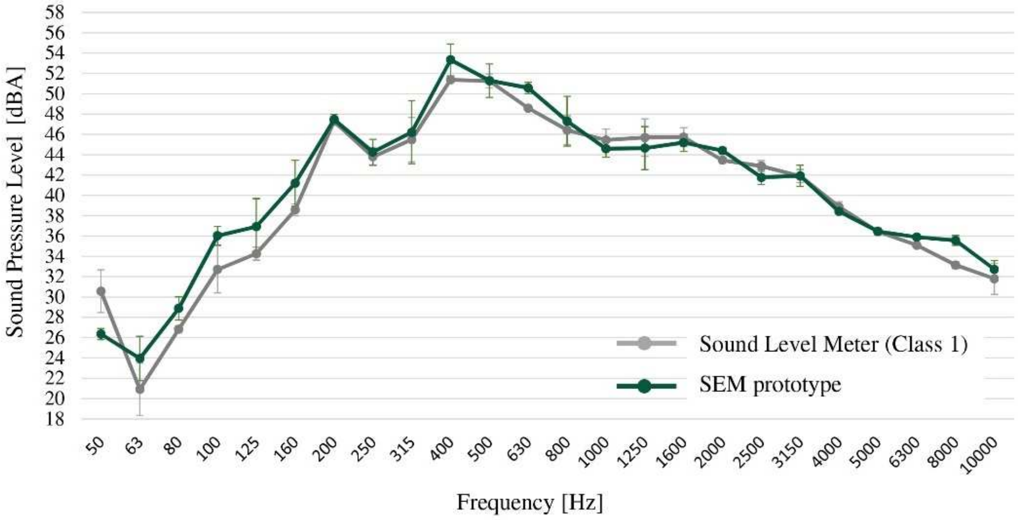


Figure 12. Comparison between frequency response of SEM prototype and class 1 Sound Level Meter related to the validation procedure in a real shared office.

Perspectives and challenges

The future prospective of the study are mainly focused on the **demonstration of the Beta prototype in a large number of shared and open-plan offices** aiming at investigating how occupants behave in the presence of SEM applying the methodology indicated in Section 3.2.

Future challenges and open questions raised from the main limitation of the Beta prototype: the second version of the algorithm (algorithm OF). Activity-based offices, the new concept of office, may generate a great number of behavioural patterns and habits since occupants can choose the right type of workplace according to activity, duration, frequency, personal interests, preferences and culture (Appel - Meulenbroek et al., 2010; Rolfö, 2018). The stochastic nature of occupant behaviour leads to increase the differences in noise levels and noise sources according to several variables, such as time of day/week, workplaces, activity and number of occupants. Therefore, the development of **a more dynamic algorithm could be a future challenge** to identify the behavioural patterns and set automatically the threshold related to the control of lighting feedback. On the other hand, algorithm complexity can be kept low for **aiming at integrating the lighting feedback system with further motivational methods** (i.e. gamification) **and communication tools** (i.e. dashboard, mobile application) with useful indicators cantered on occupants' needs and attractive information. However, some preliminary obstacles were highlighted on the effectiveness of external incentives in achieving proactive behaviour for energy saving goals, such as problems related to the usability of the ICT-based solutions, ineffectiveness of the provided feedback and little interest in viewing web pages (Asensio et al., 2018; Barthelmes et al., 2019). Further investigations on the drawbacks and positive aspects potentials that have emerged for the existing solutions are needed and the participation of users in the design process would be desirable.

Finally, a focus on different scenarios based on occupants’ interaction with the lighting feedback on their desk are needed. The choice to have hardware/software components totally independent from casing has been done to open towards **future studies on the external design of SEM based on user-cantered approach** (Frascara, 2002). Indeed, the engagement of occupants in reduction of noise generated by human speech is not only a technological challenge, but it requires a better understanding on the interaction between occupants and technological tools.

PART 3

Application of SEM device

Overview

The previous chapter was focused on the technical description of the two versions of SEM device, as well as on the testing and validation phases of the Beta prototype.

Alpha prototypes of SEM have been first applied in **primary school classrooms** where background noise levels negatively influence the learning and teaching processes, in addition to acoustic characteristics of the classrooms (Shield and Dockrell, 2004). In particular, both subjective assessments and objective measurements have proven that pupils' conversations, movement of chairs, rustling on paper and falling objects are the main noise sources in primary school classrooms (Bottalico and Astolfi, 2012, Sato and Bradley, 2008, Shield and Dockrell, 2004). As highlighted in the introductory chapter (Part 1), more research efforts are needed to solve the shortcomings on external incentives aimed to reduce noise levels by encouraging proactive behaviour and, consequently, to improve acoustic comfort and well-being. Therefore, the present chapter (Part 3) describes the **application of SEM devices** in real environments to gain a better understanding on their **interaction with occupants** and **whether background noise levels decrease based on behavioural change**. The results of **long-term monitoring campaigns performed in thirteen primary school classrooms** over 3-school years will be provided.

Moreover, **two pilot studies** are described as the starting points for future full-scale research projects. The **first one** (Section 3.1.3) has been carried out within the third noise monitoring campaign in primary school classrooms with the aim to explore the relationship between the **effects of SEM device on noise levels and teachers' vocal behaviour**. The **second pilot study** is related on the irrelevant speech noise in open-plan offices, which was largely discussed in introductory chapter (Part 1). It focuses on the **application of the Beta prototypes in a Finnish open-plan office** with the aim to 1) evaluate functionality of devices, 2) assess the performance of the preliminary version of algorithm for office (algorithm OF), and 3) design the methodology for the following monitoring campaigns.

The **research questions** of each study will be reported at the beginning of the respective paragraphs.

3.1 Long-term monitoring campaigns in primary school classrooms

The long-term monitoring campaigns have been performed over 3-school years from 2015-2016 to 2017-2018 in a primary school in Turin (Italy). The first monitoring campaign has started before the beginning of the PhD research project and was carried out by the researchers of Applied Acoustics Group. Nonetheless, the integrated data analysis has been performed within this PhD research project and, therefore, the results are presented in the following sections. Figure 13 provides an overview of goals and methodologies related to each long-term monitoring campaign.

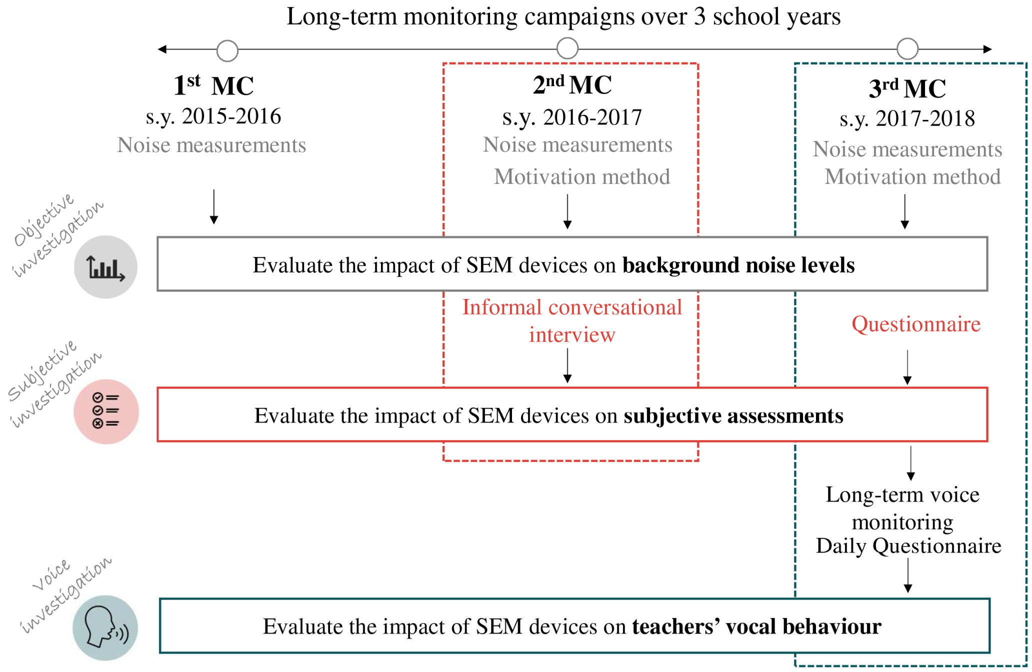


Figure 13. Overview of goals and methodologies of the long-term monitoring campaigns (MC) according to each school year (s.y.).

3.1.1 Case study

The long-term monitoring campaigns involved a primary school placed in a residential area of Turin (Italy) downtown. The school building with old style and thick masonry walls is dated back to the 1900s and it set away from main roads (Figure 14). The classrooms either faced a road with low traffic or the internal courtyard, thus the external noise is not a main source of disturbance, as confirmed by the subjective results (Section 3.1.5.3). The geometry and materials are similar among the classrooms, that are characterized by large windows, earthenware tiles on the floors, high vaulted ceilings and acoustically treated walls, the latter consisting of plasterboard tiles (1.2 x 2.4 m, with a percentage of perforation of 16%) with an air gap of 7.5 cm from the walls (Figure 15). The BS EN ISO 3382-1 standard (British Standards Institution, 2009), using the integrated impulse response method, was applied for measurements of reverberation time (T_{30}) in some classrooms, which had the average volume of 240 m^3. The mean reverberation time was 0.9 s in unoccupied condition and 0.6 s in occupied condition in the mid-frequency range (from 0.5 kHz to 1 kHz) according to the acoustical renovation and measurements described in (Astolfi et al., 2014).

Figure 14. Primary school (Torino): location and external view (Picture of Paola Boccalatte, 2014. © MuseoTorino).

Figure 15. Primary school (Torino): internal view of a type class.

3.1.2 Monitoring of background noise levels

Part 1 highlighted that background noise levels, mainly generated by pupils talking and moving, negatively influence the learning and teaching processes in classrooms (Shield and Dockrell, 2004), as well as the limitations in the applications of external incentives, such as lighting feedback, over a long-term period. In line with the limitations revealed by the literature review, this section is aimed at contributing to answer the following **research questions**:

- Does SEM device affect the background noise levels generated by pupils?
- Can independent variables, such as *teacher*, *time-band, number of pupils, day of week* and *class*, significantly affect the background noise levels?
- Can the motivational methods, based on constant feedback and/or game-based challenge, encourage pupils towards a long-term behavioural change?
- How do teachers assess the acoustic quality of classrooms? How do they perceive the presence of SEM device as an educational tool in classrooms also in relation to pupils' behaviour?

The goals and the methodologies applied in this section are highlighted in Figure 16.

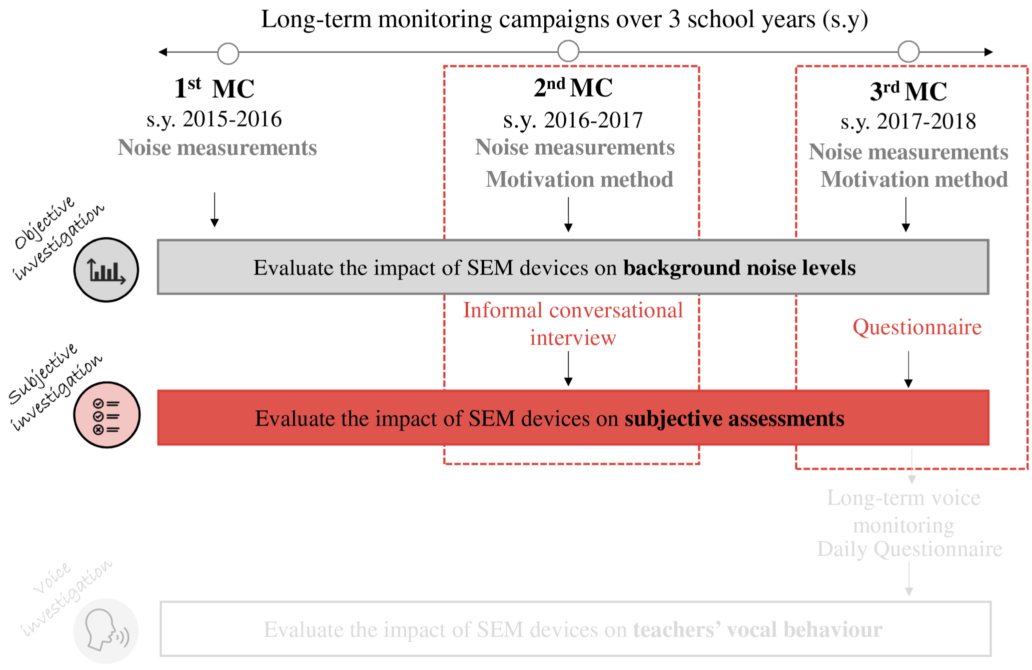


Figure 16. Overview of goals and methodologies addressed in Section 3.1.2.

3.1.2.1 Subjects and monitoring campaigns

A total of 13 school classes (4÷5 per each year) with a different number of pupils from 6 to 10 years old and 23 teachers (6÷10 per each year) were involved in the long-term monitoring campaigns; among them one took part twice. In total, 290 pupils took part to the project in order to comply the headmaster' need to allow all pupils to experience the use of SEM during the teaching activities.

The overall duration of the monitoring campaigns has been varied over the years from 6 to 16 weeks. The last week of phase 2 was excluded for the classes 4C and 5D because pupils and teachers were involved in activities out of classroom for most days of the week. The first and second monitoring campaigns were carried out from April to June, while the third one lasted from December to April. The daily monitoring period corresponded to the working day of about 8 hours, from 8.30 to 16.30 approximately, and was later filter to remove non-teaching activities, such as pupils' arrival, recreation time, lunch breaks, and playtimes in classrooms or outside. The details about long-term monitoring campaigns are reported in Table 9.

In order to easily provide the lighting feedback during the teaching activities, the Alpha prototype of SEM was located in front of pupils in each classroom (Figure 18). In the class 4O the tables were organized in small groups, thus leading to poor visibility of the lighting feedback for some students.

Table 9. Main characteristics of each monitoring campaign subdivided according to classes and the duration in weeks of phase 1 and phase 2 where the lighting feedback of SEM was switched off and on, respectively.

Monitoring campaign	School year	Duration (week)		ID Class	Number of teachers	Number of pupils
		SEM off Phase 1	SEM on Phase 2			
1st	2015-2016	2	3/4	2A	2	22-25
				3B	1	21-22
				4C	2	20-26
				5D	1	22-26
2nd	2016-2017	2	4	1E	3	16-20
				2F	2	20-25
				3G	2	16-21
				4H	3	19-21
3rd	2017-2018	6	10	1I	2	19-24
				1L	2	18-22
				2M	1	10-13
				2N	1	16-20
				4O	2	22-26

3.1.2.2 Procedure

As highlighted in Figure 16, the same procedure has been adopted in all long-term monitoring campaigns for objective data gathering, while the motivational methods and subjective assessments were introduced in the second and third monitoring campaigns.

Each campaign for **objective data** collection has been split in 2 phases distinguished by the absence/presence of the lighting feedback of SEM, as follows:

- Phase 1 (P1) ---- > the lighting feedback was **switched off** and **pupils were unaware** of the ongoing monitoring to be not influenced by an a-priori information.

- Phase 2 (P2) ----- > the lighting feedback was **switched on** and **pupils were aware** of the ongoing monitoring, indeed an information campaign was performed by researchers during the first day of this phase to explain the relationship between the colours of the lighting feedback and the noise levels produced by pupils themselves.

The background noise levels were recorded in both phases using the class 2 Sound Level Meter (ISO-TECH SLM 52N) located in the Alpha prototype (Figure 8 in Section 2.2).

An interaction between teachers and SEM was needed during the long-term monitoring campaigns: teachers were invited to switch off/on the prototypes and to note the information in a daily logbook to gather independent variables (fixed factors), such as type of activity and the respective time-slot, own name, number of pupils, day of week and possible noise events coming from outside the classroom.

It is largely known that "Motivation has long been viewed as a key element of learning" (Frey and Fisher, 2010). Several variables can affect the intrinsic motivation of students, such as self-determination, feelings of competence, feedback, task challenge or difficulty, thus different teaching methods can be used to motivate students, such as creative activities, cooperative groups, brainstorming, role-playing, games with an added pedagogical value of fun and competition and visual aids using modern technology (Brewer et al., 1988, Orland et al., 2014). Therefore, in addition to SEM technology, a **motivational method** based on constant feedback and/or game-based challenge was applied to promote a constant interaction between pupils and SEM and, finally, the fulfilment of long-term behavioural changes.

The need to introduce the motivation methods arose from three reasons: 1) the preliminary results of the first monitoring campaign in which the significant decreases of noise levels were particularly concentrated in the first week (described in detail in Section 3.1.5.4); 2) the tendency to adopt several strategies to motivate people towards more aware behaviour in order to keep the noise under control in densely occupied spaces (Brown et al., 2016; Asensio et al., 2018); and 3) the teachers' opinions related to the fact that pupils could pay more attention to the lighting feedback in the early stages of the monitoring campaign because this is perceived as a novelty.

The motivational methods varied in the two monitoring campaigns. In the second monitoring campaign, teachers were invited to provide the pupils with a feedback on the quantity of green, yellow and red light colours obtained during lessons, according to the statistics provided by a mobile app (Figure 17). This strategy was proposed by researcher during the focus group, however teachers were willing to use it. Moreover, a game-based challenge between classes was proposed by some teachers during the brainstorming. They considered this latter as a useful strategy to obtain the fulfilment of long-term behavioural changes. According to (Brewer et al., 1988, Orland et al., 2014), games with an added pedagogical value of fun and competition can be a method to motivate students. The game-based challenge ended with the communication of the colour-based ranking of the four classes to pupils by the researcher at the end of the monitoring campaign.

In the third monitoring campaign, the abovementioned motivational approaches were excluded mainly to meet the teachers' requests arose during the focus group. This change also arose in response to the preliminary disappointing results of the second monitoring campaign (described in detail in Section 3.1.5.4). A new motivational method was defined in collaboration with teachers: this was based on the constant feedback provided by the researcher on the results obtained during the entire week of monitoring. In particular, the trend of green, yellow and red light colours was communicated at the beginning of the following week through a plot on the whiteboard (Figure 18) and a report containing the results distributed in each involved class. This motivational method was technologically simpler than the previous one, but it required an increased time and work efforts for the researcher that had to be in classroom at the beginning of each week of phase 2.

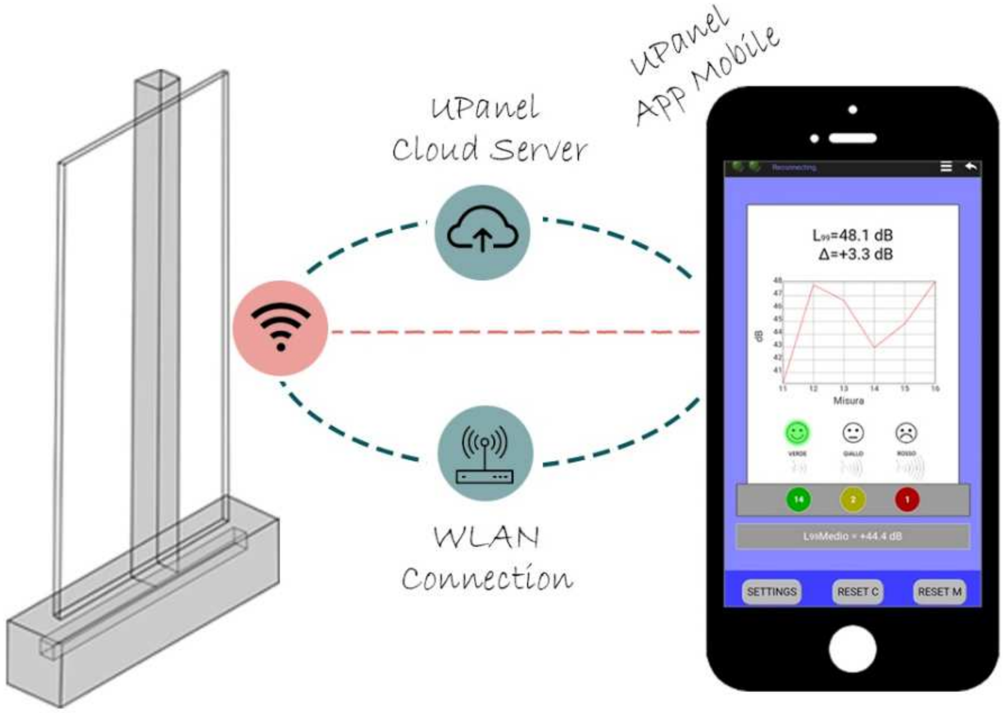


Figure 17. Network connection between SEM device and mobile app used in the second monitoring campaign. User interface with the trend of green, yellow and red light colours and average value of statistical noise levels was also shown.

Figure 18. Communication of the trend of green, yellow and red light colours by researcher to students during the phase 2 of the third monitoring campaign.

3.1.2.3 Data processing of noise monitorings

Data recorded by the Sound Level Meter were real-time transferred to a cloud server and later downloaded into an Excel spreadsheet on a personal computer for post-processing.

In accordance with Bottalico and Astolfi (2012) and Calosso et al. (2017) the overall A-weighted background noise level generated by pupils was measured during traditional lessons using the A-weighted level exceeded for 90% of the considered time (L_{A90} in dB).

The present dissertation has focused on time-slots of traditional lessons (plenary), where students sit at their desks and listen to the teacher who is speaking at her/his desk or close to the blackboard (Bottalico and Astolfi, 2012). Traditional lessons require students to hold a higher cognitive effort for learning and understanding the contents of the lessons, therefore low background noise levels are needed. For this reason, the use of SEM has been preliminary addressed for this type of lesson. Recreation time, lunch breaks and playtimes have been excluded. The time-slots of traditional lesson have been manually selected according to the starting and ending points indicated in the daily logbook filled in by teachers every day. These time-slots were selected within three time-bands according to the schedule of the working day, that are as follows:

- M1: morning period before the recreation time, that ranged by about 8.30-10.30
- M2: morning period after the recreation time, that ranged by about 10.45-12.30

- A3: afternoon period after lunch break, that ranged by about 14.30-16.15

The starting and ending point of the three time-bands can vary according to the schedule of each every day; however, the overall duration of each traditional lesson can range between 30 min and 120 min.

It is important to specify that some teachers were excluded from the present study for the following reasons: 1) they filled in the daily logbook approximately, 2) their teaching method was mainly based on group lessons and 3) the presence of different substitute teachers due to the absence of tenured teacher.

3.1.2.4 Subjective assessments

As highlighted in Figure 16, the subjective assessments were introduced in the second and third monitoring campaigns in order to evaluate how the acoustic environment was perceived by teachers, and to gather information about the usefulness of lighting feedback.

In the second monitoring campaign an informal conversational interview (Wildemuth, 2009) was performed with the aim of better understanding the teachers' observations related to the presence of SEM in the classroom. In the third monitoring campaign a questionnaire was submitted to teachers. It was drawn up according to the questionnaire used in (Bottalico and Astolfi, 2012) and extended to include questions on the use of SEM, defined according to the themes emerged from informal conversational interview. A cover letter reported at the beginning of the questionnaire specified its purposes, which were also personally explained by researcher to teachers.

The final version, organized in 3 sections, contained a total of 24 questions including the 8 background questions. In the second section, questions were based on 5-point labelled with opposite descriptors according to the original questionnaire, while the labels were present for the entire 5-point scale in the third section. A total of 2 open-ended questions and two yes/no questions with the option to justify the choice were also used. For each section, the questionnaire investigated: 1) background information, 2) environmental acoustic quality of classroom, and 3) the use of SEM devices as an educational tool. Tables 10 and 11 summarize the survey questions of the second and third sections, respectively, while the whole paper questionnaire is reported in Annex B.

The questionnaire was administrated to 8 teachers in all 5 classes at the end of the third monitoring campaign. Teachers' age ranged between 38 and 60 years, with a mean age of 48.4. Teaching experience varied between 13 and 21 years for 38% of teachers, while 25% and 38% of them had less than 6 years and more than 20 years, respectively. Some missing answers were found in the questionnaires.

Table 10. Survey Section 2: environmental acoustic quality of classroom. Q9 is an open-ended question.

ID	Topic	Scale and descriptors
Q1	Influence of acoustics on teaching	Very little (1) – A great deal (5)
Q2	Noise intensity	Very low (1) – Very high (5)
Q3	Noise intensity, disturbance and frequency of occurrence for different sources	Very low (1) – Very high (5)
Q4	Reverberation of the sounds and voices	Very dry (1) – Very reverberant (5)
Q5	Speech comprehension	I don't understand anything (1) – I understand all (5)
Q6	Teachers' vocal effort	Very low (1) – Very raised (5)
Q7	Satisfaction with classroom acoustics	Strongly agree (1) – Strongly disagree (5)
Q8	Occurrence of consequences related to classroom acoustics	Never (1) – Very often (5)
Q9	Strategies to reduce vocal effort and to improve intelligibility of the speech	-

Table 11. Survey Section 3: the use of SEM devices as an educational tool. Q16 is an open-ended question.

ID	Topic	Scale and descriptors
Q10	Satisfaction with SEM device in terms of noise for different activities	Not at all (1) – Extremely (5)
Q11	The usefulness of SEM device in terms of vocal effort	Yes/No + Justify the choice
Q12	Attention of pupils to SEM device	Not at all (1) – Extremely (5)
Q13	Long-term improvement of pupils' behaviour	Not at all (1) – Extremely (5)
Q14	The usefulness of constant feedback provided by researchers	Yes/No + Justify the choice
Q15	The interest in the use of SEM devices for noise reduction	Not at all interested (1) – Very interested (5)
Q16	General opinions on SEM device	-

3.1.3 Pilot study: long-term monitoring of teachers' vocal behaviour

The purpose of the activity described in the previous section was to investigate the possible changes in pupils' behaviour for noise reduction induced by SEM. However, the pilot study has a second purpose: to investigate how the noise reduction led by SEM can change the teachers' vocal activity. This purpose is achieved through long-term voice monitoring sessions, which consist of an acquisition lasting the entire working day of teacher (roughly 3 to 4 hours per day).

Literature agrees in stating that teachers tend to excessively raise their voice level in order to improve intelligibility under noisy condition and poor classroom acoustics (Calosso et al., 2017; Pelegrín-García et al., 2011; Puglisi et al., 2017), generating possible negative consequences on their vocal apparatus (Bottalico and Astolfi, 2012; Vilkman, 2000). Åhlander et al. (2012) found that the interplay between personal behaviour and work environment is the cause of voice dysfunction for teachers that self-reported voice problems. In line with these findings, SEM could play a crucial and challenging role in voice production during teaching hours. When the background noise levels are reduced, voice levels are expected to decrease too, according to the Lombard Effect, that is the involuntary tendency of speakers to increase their voice level when speaking in loud noise to enhance the audibility of their voice (Harlan and Bernard, 1971). In this perspective, SEM could be used as a tool supporting teachers to adapt voice level to noise conditions in real time and promoting more aware vocal behaviours. Furthermore, teachers may use SEM device as a communication tool to promote awareness among pupils about noise conditions in real time and to avoid raising the voice to calm down the pupils (e.g., the red-colored lighting feedback can somehow replace teachers shouting and become the main strategy for pupils to have a proactive behaviour).

In this framework, the present pilot study is a starting point that is mainly aimed at **proposing a methodology for long-term monitoring of teachers' vocal activity in relation to the presence of the noise monitoring system with lighting feedback**. Secondly, it is aimed at preliminary contributing to answer the following **research questions**:

- Do the teachers' voice levels decrease when the lighting feedback of SEM devices is switched on in classrooms?
- Is there a significant difference in terms of voice levels and background noise levels when SEM devices are switched on, independently from the subjects?
- How does SEM device affect the vocal effort of each teacher and the background noise levels, class-by-class?
- How do teachers perceive their vocal status, noise condition and voice intensity with and without SEM devices?

The main goals and the methodologies applied in this section are highlighted in Figure 19.

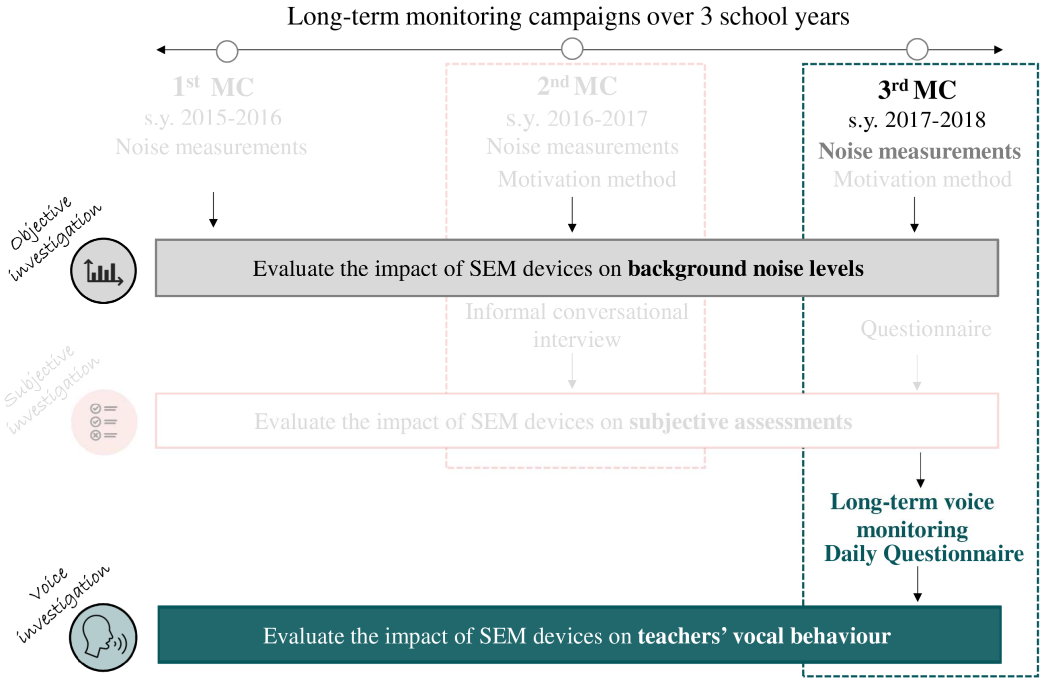


Figure 19. Overview of goals and methodologies addressed in Section 3.1.3.

3.1.3.1 Teachers sample

Vocal activities of one male and six female teachers were monitored from 2 to 4 working days (3-4 hours per each monitoring) over two different time periods, that corresponded to the phase 1 (P1) and phase 2 (P2) of the third noise monitoring campaign, with and without the SEM lighting feedback, respectively. The vocal activity of teachers was monitored during the morning and the afternoon period according to the working schedule of Italian teachers, that is based on two different shifts, from 8.30 to 12.30 and from 12.30 to 16.30. Due to some failures of the recording system detected during the post-processing phase (described in detail in Section 3.1.3.3.), the sample is reduced to four female teachers.

The long-term voice monitoring was performed in the middle of the school year, from January to March, with a distance between the phases P1 and P2 from 4 to 6 weeks. According to the willingness of teachers towards the voice monitoring, four classes from first to fourth grade were involved, including 12 to 25 pupils each depending on the day and the class, with ages ranging from 6 to 9 years. Teachers' age ranged between 38 and 60 years, with a mean age of 51.

Table 12 shows their characteristics and the corresponding classes, including the number of the pair of long-term monitoring and the period of the working day for each teacher.

Table 12. Characteristics of the investigated teachers and the respective classes. Code of each pair of long-term monitoring and the period of the working day, morning (M) and afternoon (A), of each one pair according to phases P1 and P2 are also shown.

ID Teacher	Age	ID Class	Number of pupils during long-term monitoring	ID pair of long-term monitoring	Period of the working day	
					P1	P2
C	38	2M	20-22	1	M	A
D	55	2M	12-14	1	M	M
				2	A	M
G	50	2N	17-19	1	M	M
E	60	4O	23-25	1	M	M

3.1.3.2 Recording equipment and procedure

The long-term voice monitoring was performed using a portable vocal analyzer, based on the Voice Care technology, that has been developed at the Politecnico di Torino by Carullo et al. (Carullo et al., 2013, 2014; Carullo, Vallan, et al., 2015). This device allows to perform long-term voice monitoring (several hours per day) since it has a negligible sensitivity to background noise (Carullo, Casassa, et al., 2015), indeed it has been widely used for in-field monitorings on teachers' vocal behaviour (Bottalico and Astolfi, 2012; Calosso et al., 2017; Puglisi et al., 2017). The portable vocal analyzer is composed of a collar integrating a Piezoelectric Contact Microphone (PCM, HX-505-1-1, Shenzhen, China), which is to be placed near the jugular notch to sense the acceleration of the skin generated by the vibration of the vocal folds. The sensor is connected to a smartphone (Samsung SM-G310Hn) used to record the signals with a sampling rate of 22050 Hz and 16 bit of resolution; the registration is managed through an application, namely the Vocal Holter App (by PR.O.Voice s.r.l., Turin, Italy) (Carullo, Vallan, et al., 2015).

The background noise level was monitored in classrooms using a sample period of 5 s through the class 2 Sound Level Meter (ISO-TECH SLM 52N) located in the Alpha prototype of SEM device.

The procedure for voice monitoring was carried out based on the previous studies, where the teachers' vocal behaviour was recorded during their activity for long-terms, i.e. either one week (Puglisi et al., 2017) or one year (Calosso et al., 2017) monitoring. In short, each voice monitoring consisted of two steps, that are reported as follows:

1) calibration procedure with a reference microphone performed in a quiet room of the school;
2) voice monitoring performed for long-term during the teaching activity in classroom.

The calibration procedure aimed at accurately refer the sound pressure level (SPL in dB) measured in air to the voltage signals sensed at the base of the neck. The school library was used for this purpose, where the average A-weighted equivalent background noise level (L_{Aeq}) was equal to 37.6 dB (s.d. = 2.6 dB) according to measurements performed in three different days. The calibration procedure was carried out using a class 1 Sound Level Meter with omnidirectional microphone in air (SLM, XL2, NTi Audio) and the contact-microphone (PCM, HX-505-1-1, Shenzhen, China) connected to the smartphone provided to each teacher. They were asked to perform the following activities:

a) vocalizing for 3 to 5 short times the vowel /a/ with increasing intensity and to repeat this task other two times, alternating few s of silence between the repetitions;
b) vocalizing a sustained vowel /a/ maintained from 5 to 10 sec;
c) performing a free conversation of about 1 min using a comfortable pitch of voice.

Each teacher was standing in front of the omni-directional microphone in air at the distance of 17 cm on axis in the calibration activities a) and b), instead, the activity c) was performed with the teacher standing randomly in the room at one meter from the researcher who supervised the monitoring.

Each long-term voice monitoring was started after the calibration procedure; thus teachers were equipped with the contact-microphone connected to the smartphone located in a small bag for the entire lesson (Figure 20).

Figure 20. An example of long-term voice monitoring in a classroom during P2 with the lighting of SEM was switched on. The contact microphone connected to the smartphone located in the small bag are marked whit white dots shape.

3.1.3.3 Data processing

Data recorded by the SLM and smartphone were transferred to a personal computer for post-processing. Only the part of vowel /a/ scales related to the calibration activity a), and the time-slot regarding to traditional lesson of the long-term voice monitoring have been selected to investigate the teachers' voice use in relation with both phases, P1 and P2, of noise monitoring.

Traditional (plenary) lessons have been chosen since they require the most demanding vocal activity for teachers due to a typical phonation time percentage of about 30% (Hunter and Titze, 2009; Puglisi et al., 2017). Moreover, traditional lessons require students to hold a high cognitive effort for learning and understanding the contents of the lessons, therefore low background noise levels are needed. For this reason, the use of SEM has been preliminary focused on this type of lesson, as mentioned in Section 3.1.2.3.

The time-slots of the traditional lessons have been detected and manually selected in the wav files using Audacity software according to the starting and ending points indicated in the timesheets filled in by teachers during each long-term voice monitoring (described in detail in the following section). In a previous study performed in secondary schools (Calosso et al., 2017), the detection of the time-slot of traditional lessons was carried out by the researchers present in classrooms. This method was not adopted in the present study since an external operator may disturb occupants or cause the Hawthorne effect, which assumes that "subjects may behave differently, because they are aware that they are being studied" (Wagner and Brien, 2018; Adair 2000; Seligman et al., 1978). Recreation time, lunch breaks and playtimes have been excluded by the analysis, and the duration of each time-slot can vary between 100 min and 120 min. As mentioned above, the failure of some recording led to a final sample consisting of 10 signals.

A processing program allows to extract from the recorded signal several parameters, such as the sound pressure level (SPL in dB) at a certain distance from the speaker's mouth, the fundamental frequency (F0 in Hz) and the voicing time percentage (Dt% in Hz). In order to investigate the vocal effort of teachers, the sound pressure level of voiced speech at 1 m from the teacher's mouth (SPL_{1m}) was calculated according to the method indicated in previous studies (Calosso et al., 2017; Carullo, Vallan, et al., 2015; Puglisi et al., 2017). In short, ad-hoc MATLAB 2017 scripts (MathWorks, Natick, MA) were used to align in time the two signals recorded by PCM and SLM and select the same time segments, containing one or more vowel /a/ scales. Then, the best-fit regression function for the voltage signals sensed at the base of the neck by PCM against the SPLs measured by SLM was generated. SPL occurrences for each long-term voice monitoring were estimated according to the best-fit regression function. The SPL values were estimated 1 m far from the speaker's mouth (SPL_{1m}) according to the free-field sound propagation theory to obtain the vocal effort of subjects to comply with ANSI S3.5–1997 (ASA, 2012). During the post-processing, the SPL values were sampled every 5 s according to the data samples of noise in order to temporally synchronize the two signals, as well as the exclusion of unvoiced frames was also performed.

3.1.3.4 Subjective assessments

According to the protocol used in previous studies (Bottalico and Astolfi, 2012), teachers were invited to fill in a timesheet at the end of the working day, as mentioned above, made of two sections. In the first one, teachers were asked to report the background information and the type of activity, e.g. traditional lesson, shared lesson, group activity, performed during the long-term voice monitoring, as well as to record any change in teaching activity. In the second section, they were asked to evaluate the vocal status, noise condition and voice intensity perceived during the lesson compared to an ideal condition, e.g. no noise at the beginning of the day and/or empty room, using a visual analogue scales (VAS), that is a 10-cm line anchored at the ends by the opposite descriptors. Table 13 reports the three questions and the respective descriptors. The complete version of timesheet is reported in Annex C

Table 13. Questionnaire Section 2: vocal status, noise condition and voice intensity

ID	Question	Descriptors
Q1	Evaluate your vocal status compared to that perceived at beginning of the day	No voice problems - Severe voice problems
Q2	Evaluate the intensity of noise in the classroom with respect to the situation of unoccupied classroom and empty school at the beginning of the day	Very low – Very high
Q3	I had to raise the voice levels to compared to the ones that I should use in a condition without background noise and reverberation	Strongly agree – Strongly disagree

3.1.4 Data Analysis

Several analyses have been carried out with the purpose of addressing the research questions mentioned in Sections 3.1.2 and 3.1.3 related to monitoring background noise levels and to the pilot study on teachers' vocal behaviour in the presence of SEM devices, respectively.

The software used for the analysis is MATLAB 2017 (MA, MathWorks, Natick, MA), SPSS software (SP, IBM Statistics 20, IBM, Armonk, NY, USA) and G*Power 3 (Faul et al., 2007). Statistical tests and data analysis are summarized in Table 14, as well as the respective goals, and dependent and independent variables.

Before the explanation of each data analysis, the **description of terms** indicated in Table 14 are reported as follows:

- **L_{A90} occurrences distribution** consists in the L_{A90} values measured every 5 s of a specific working day in each class.

- **$L_{A90,mean}$** is the average value of the occurrence distribution of L_{A90} measured every 5 s of a specific working day in each class.
- **SPL_{1m} occurrences distribution** consists in the SPL_{1m} values measured every 5 s during the traditional lesson of a specific long-term monitoring in each class.
- **$SPL_{min,1m}$** is the minimum value of sound pressure level at 1 m (SPL_{1m}) from the teacher's mouth measured every 5 s within a range of 3 dB of L_{A90}. An example of this calculation is reported in Figure 21.

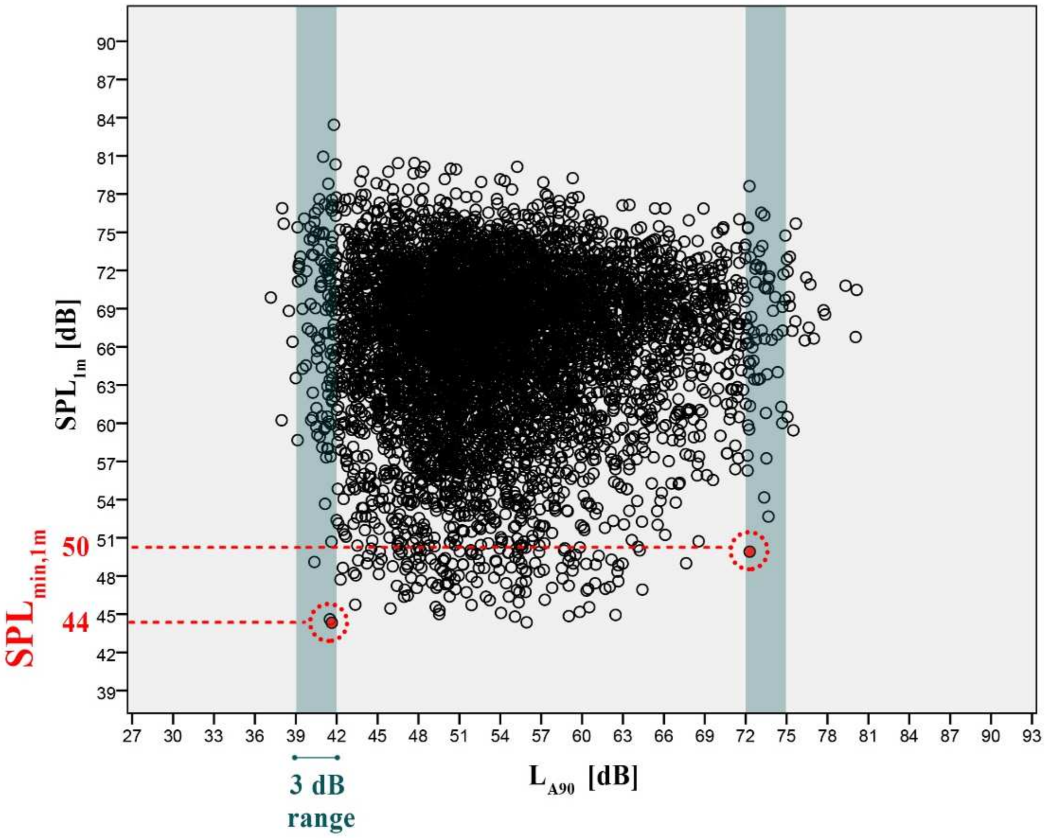


Figure 21. Examples of the minimum values of sound pressure level at 1 m ($SPL_{min,1m}$) from the teacher's mouth (44 dB, 50 dB) within a range of 3 dB of L_{A90} (39-42 dB, 72-75 dB).

- **P1 and P2** indicate phase 1 and phase 2 of the monitoring campaigns where the conditions of the lighting feedback changes. As reported in Section 3.1.2.2, it was switched off/on in P1 and P2, respectively.
- **Fixed factors** are name of the teacher, number of pupils, day of week, class, type of lesson and the respective time-slot within the three time-bands previous indicated in Section 3.1.2.3 (morning period before and after recreation time, and afternoon period).

Table 14. A summary of data analysis and statistical tests with the respective objectives. The identification code, dependent (Dep.) and independent (Ind.) variables and software (SW) are also reported for each analysis. The following abbreviations are used to indicate the software: "S" for SPSS and "M" for MATLAB.

ID	Dep./Ind. Variable	Statistical Test/Analysis	SW	Objective of Statistical Test/Analysis
A1	$L_{A90,mean}$	One-way ANOVA	S	Estimate the significance of the fixed factor, that is *class*, on background noise levels separately for each monitoring campaign.
A2	$L_{A90,mean}$ / Lighting feedback	Independent Sample *t*-test or Mann-Whitney U (MWU) test in its bilateral version (two-tailed)	S	Calculate the significance of the differences in $L_{A90,mean}$ values between P1 and P2.
A3	$L_{A90,mean}$	Two-factors analysis of variance (ANOVA)	S	Estimate separately the effects of fixed factors (teacher, time-band, day of week and number of pupils) on background noise levels and their interaction with the lighting feedback.
A4	L_{A90} occurrences distribution (o.d.) / Lighting feedback	Two-tailed MWU test	S	Examine the significance of the differences in the independent pair of L_{A90} o.d. related to the two days of P1 and P2.
		Right-tailed MWU test	M	Verify the acceptance of the right-tailed alternative hypothesis H1: $M_{off} > M_{on}$ where M_{off} and M_{on} are the mean ranks of L_{A90} o.d. related to the two days of P1 and P2, respectively.
A5	$L_{A90,mean}$ / Lighting feedback	Two-tailed Wilcoxon signed-rank test	S	Calculate the significance of the differences in $L_{A90,mean}$ values between P1 and P2 when the fixed factors are controlled.
A6	$L_{A90,mean}$	One-way ANOVA	S	Estimate the significance of the *period of monitoring* on background noise levels measured in P2.
A7	$SPL_{min,1m}$ / L_{A90}	Linear Regression	-	Investigate the relationships between the $SPL_{min,1m}$ and L_{A90} according to P1 and P2.
A8	L_{A90} o.d. SPL_{1m} o.d./ Lighting feedback	Two-tailed MWU test	S	Examine the significance of the differences in the independent pair of L_{A90} and SPL_{1m} o.d. of the two long-term monitorings related to P1 and P2.
		Right-tailed MWU test	M	Verify the acceptance of the right-tailed alternative hypothesis H1: $M_{off} > M_{on}$ where M_{off} and M_{on} are the medians or mean ranks of L_{A90} and SPL_{1m} o.d. related to the two long-term monitorings related to P1 and P2.

Data Analysis A1

Goal: to investigate the significance of the effect of one fixed factor, that is the *class*, on background noise levels in order to verify the necessity to perform the subsequent analyses considering the classes separately or together.

Test and procedure: the one-way analysis of variance (ANOVA) was applied on the averaged $L_{A90,mean}$ values separately for the three monitoring campaigns. The assumptions of normal distribution and homogeneity of variance was assessed through the Shapiro–Wilk test and Levene's Test (Field, 2000) on each data sample. The assessment of the strength of the relationship between the investigated variables, that are *class* and background noise levels, was determined through the effect sizes. In particular, Cohen's *f* equation based on the relationship between the partial Eta-squared (η_p^2) and *f* (Cohen, 2013) was calculated using G*Power 3.

The results of this analysis are reported at the beginning of Section 3.1.5.

Data Analysis A2

Goal: to investigate the significance of the differences in $L_{A90,mean}$ values between phases 1 and 2, where the lighting conditions differed from each other.

Test and procedure: $L_{A90,mean}$ values were divided into Group 1 and Group 2, where the former is composed of data measured in each day of phase 1, and the latter includes data related to each day of phase 2. At the beginning of each statistical analysis, the boxplots were used for spotting and removing the outliers and the distributions were checked to verify the assumption of normality using the Shapiro–Wilk test. In cases where a significant deviation from normality was found, a non-parametric test, the Mann-Whitney U (MWU) test, was used (Sigel,1988), while a parametric test, the Independent Sample (IS) *t*-test, was applied when both data samples were normally distributed (Sheskin, 2007). Estimates of effect sizes were manually calculated through Cohen's *d*: the equation with the weighted pooled standard deviation was used for IS t-test, and the transformation from partial Eta-squared to *d* was done for MWU test according to (Cohen, 2013).

It was assumed that the data samples of phase 1 and phase 2 were independent in the two phases since the fixed factors (i.e. teacher, day of the week, time-band of the lesson and number of pupils) were different between both phases, as well as other variables (i.e. the contents and activities of the lessons and daily classroom conditions).

The results are reported in Table 15 of Section 3.1.5.1. This analysis allows to compare the results with previous studies, which have investigated the effect of the visual feedback on noise levels without controlling fixed factors.

Data Analysis A3

Goal: to estimate the effects of fixed factors, that are *teacher, time-band, day of week* and *number of pupils,* and their interaction with the lighting feedback on background noise levels.

Test and procedure: the two-factors analysis of variance (ANOVA) between-groups (Field, 2000) was performed to estimate the effects of each fixed factor on background noise levels and their interaction with the lighting feedback. The analysis was carried out separately for each class. The two samples grouped by the conditions of lighting feedback was not considered repeated data because some variables could be different in the class in the two phases (i.e. daily classroom conditions, the contents and the activities of the lessons). The assumptions of normal distribution and homogeneity of variance was assessed through the Shapiro–Wilk test and Levene's Test (Field, 2000) for each model of two-factors ANOVA analysis. In case of violation of the assumptions the non-parametric tests, MWU test and Kruskal Wallis (KW) test, were applied in order to investigate, respectively, the significance of the differences on background noise levels between two or more independent groups according to the two lighting feedback conditions. Some classes were excluded by the two-factors ANOVA analysis due to missing or little number of data in each group, as well as in the classes where there was only one teacher. Estimates of effect sizes was determined through Cohen's *f* (Cohen, 2013) using G*Power 3, as well as in data analysis A1.

The results of this analysis are reported in Table 16 of Section 3.1.5.2.

Data Analysis A4

Goal: to investigate the significance of the differences in L_{A90} occurrences distributions related to two days of phase 1 and phase 2 controlling the fixed factors in order to evaluate the effect of SEM lighting feedback on background noise levels.

Test and procedure: the manual selection of the pair of independent L_{A90} occurrences distributions related to two days of P1 and P2, respectively, was performed according to the characteristic of the fixed factors before the statistical test. As mentioned in Section 3.1.2.2., the fixed factors are the following: *type of lesson* and its *time-band, teacher, number of pupils* and *day of week*. These were selected based on previous studies: for example Shield and Dockrell (2004) found that the variation of noise levels was related to classroom activities and number of pupils in classroom. Moreover, the difference in the use of voice level between morning and afternoon working period were also obtained in (Bottalico and Astolfi, 2012). Massonnié et al. (2019) reported that children are exposed to different noise levels in classrooms depending on time of day and type of activity. An example of a comparison of L_{A90} occurrences distributions selected according to the fixed variables is shown in Figure 22.

The MWU test was applied for all cases based on the comparison of L_{A90} occurrences distributions related to the same class and teacher, the same week-day and exactly the same time-band in two different days with SEM lighting feedback conditions switched off (P1) and switched on (P2), respectively. The type of activity and the contents of the lessons could be different between the days of the both phases, despite the traditional lessons were only used in the analysis according to the daily logbook. Moreover, the same pupils may not always be present in classroom since the number can vary in the both phases with an average difference by about 2 pupils between the two data samples. In addition, other variables that are not directly controllable by the researcher could also differ (i.e. daily classroom conditions). Given those premises, the L_{A90} samples of phase 1 are not exactly "paired" with the ones of phase 2 since there is not a strict paired relationship between the two groups of observations, as required by the paired samples. Therefore, MWU test for independent samples was used in the analysis. The bilateral (two-tailed) MWU test was preliminary applied to assess the significance of the differences in the 547 pairs of independent L_{A90} occurrences distributions. The unilateral (right-tailed) MWU test was used to verify whether the following hypothesis can be accepted: H_1: $M_{off} > M_{on}$ where M_{off} and M_{on} are the mean ranks of L_{A90} occurrences distributions related to the two days of phase 1 and phase 2.

The results of this analysis are reported in Table 17 of Section 3.1.5.3.

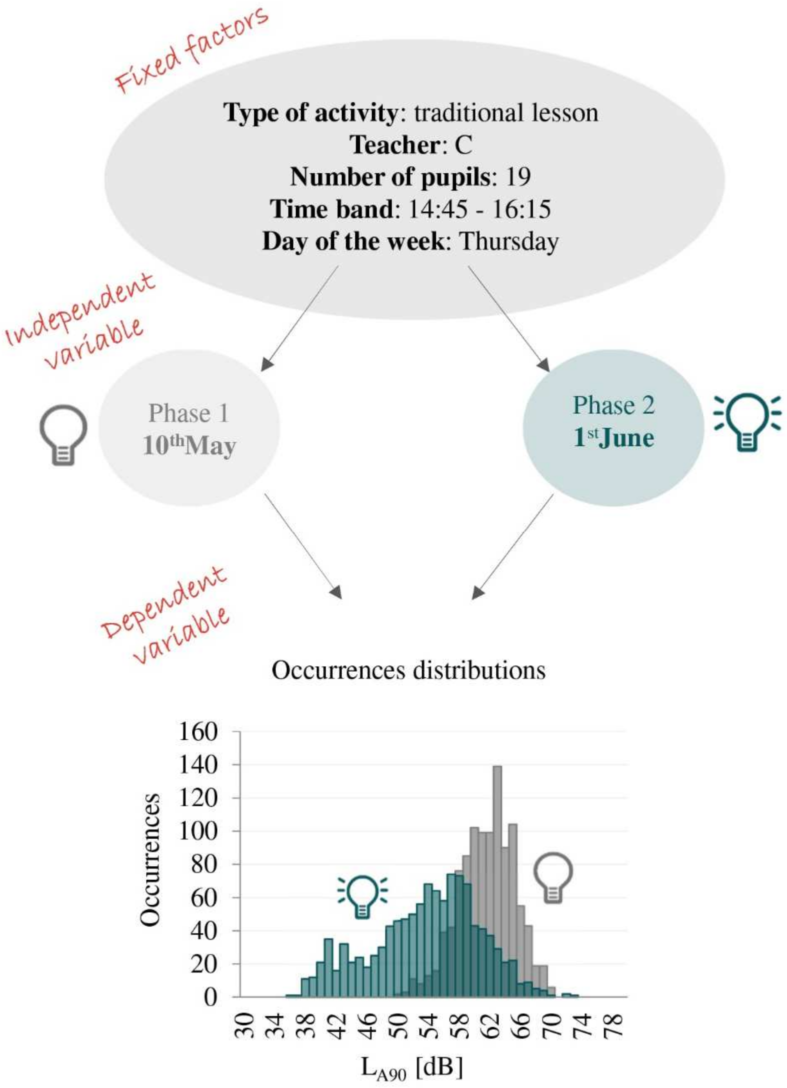


Figure 22. An example of a pair of independent L_{A90} occurrences distributions related to phase 1 (grey colour) and phase 2 (green colour) where the fixed variables are the same. The reduction of background noise levels was found in the presence of the lighting feedback (improvement).

Data Analysis A5

Goal: to investigate the significance of the differences in $L_{A90,mean}$ values between phases 1 and 2 when the fixed factors are controlled.

Test and procedure: Wilcoxon signed-rank test, was applied to $L_{A90,mean}$ values following a different approach compared to data analysis A4. The pair of $L_{A90,mean}$ values were considered dependent in order to compare two sets of mean scores where the fixed factors are the same. Indeed, data sample of each class consists of the paired mean values of L_{A90} occurrences distributions of phase 1 and phase 2. Since MWU test would have ignored the pair of mean scores in the ranking process bypassing the control of fixed factors, Wilcoxon signed-rank test has been used. Moreover, it is assumed that the average L_{A90} values could be less influenced by the uncontrolled variables (i.e. contents of the lessons, daily classroom conditions) compared to L_{A90} occurrences distributions, which consist of L_{A90} values were measured every 5 s. Estimates of effect sizes were calculated through the transformation from *r* (Rosenthal, 1991; Field, 2018) to Cohen's *d* according to (Lenhard, W. & Lenhard, A., 2016).

The results of this analysis are reported in Table 18 of Section 3.1.5.3.

Data Analysis A6

Goal: to estimate the long-term effect of the two motivational methods for each class on average $L_{A90,mean}$ values measured in P2. The motivational methods were supposed to lead to positive effect on long-term maintenance of proactive behaviours of pupils whether the background noise levels follow a decreasing trend over the entire monitoring with the lighting feedback on.

Test and procedure: the period of phase 2 was divided into two or three groups according to the entire number of weeks of the monitoring campaigns. As shown in Figure 23, two groups were identified in the second monitoring campaign and three groups in the third ones.

The one-way analysis of variance (ANOVA) was applied to the average $L_{A90,mean}$ values to investigate the significance of the effect of one fixed factor, that is *period of monitoring*, on background noise levels. Estimates of effect sizes were determined through Cohen's *f* (Cohen, 2013) using G*Power 3. Thus, the statistical test was adopted to verify the hypothesis that a motivational method leads to a significantly decreasing trend of background noise levels over the period when the lighting feedback of SEM was switched on (P2). The KW and MWU tests were used when the assumptions of normal distribution and homogeneity of variance were violated, as well as for little numerosity of data sample of each group. In order to estimate the effect sizes the transformation from partial Eta-squared to *d* was done for MWU test according to (Cohen, 2013; Lenhard W. and Lenhard A., 2016). The statistical tests were not applied on data collected in the second monitoring campaign because there was a small number of average $L_{A90,mean}$ values in some groups, thus only a trend was evaluated.

The results of this analysis are reported in Figure 35 and Figure 36 of Section 3.1.5.4.

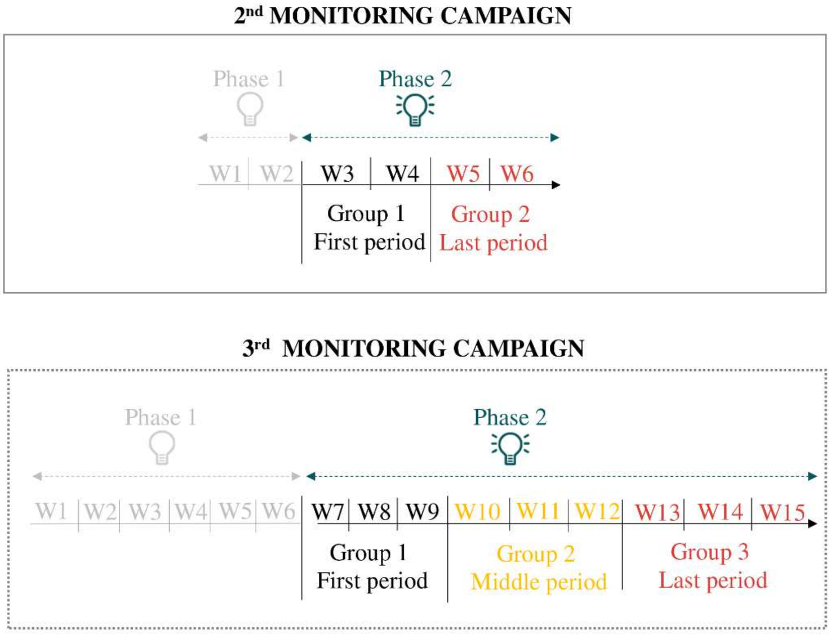


Figure 23. The division into two and three groups according to total number of weeks of the phase 2 in the second and third monitoring campaigns, respectively.

The following data analyses are related to the pilot study on long-term monitoring of teachers' vocal behaviour.

Data Analysis A7

Goal: to investigate the relationships between the $SPL_{min,1m}$ and L_{A90} according to phase 1 and phase 2 and detect the Lombard effect.

Procedure: The $SPL_{min,1m}$ is evaluated within a range of 3 dB of L_{A90} as indicated in Figure 20, and the regression line for the two data samples of phase 1 and phase 2 is fit.

The results of this analysis are reported in Figure 44 of Section 3.1.6.1.

Data Analysis A8

Goal: to verify whether the following right-tailed alternative hypothesis can be accepted: H_1: $M_{off} > M_{on}$ where M_{off} and M_{on} are the medians or mean ranks of L_{A90} and SPL_{1m} occurrences distributions related to the two long-term monitorings of the two days of P1 and P2. The significance of the differences in the pair of L_{A90} and SPL_{1m} occurrences distributions was preliminary examined maintaining *teacher*, *class* and *type of activity* as fixed factors. Time-bands of the traditional lessons and day of week were not the same in each pair of L_{A90} and SPL_{1m} occurrences distributions of the long-term monitorings due to the small size sample.

Procedure: the same procedure used in the statistical analysis A3 was performed.

The results of this analysis are reported in Table 22 of Section 3.1.6.1.

3.1.5 Results and discussion: monitoring of background noise levels

According to data analysis A1 and based on the one-way ANOVA, a significant effect of *class* on background noise levels was found in the first monitoring campaign ($F(3,86) = 3.49$, $p = 0.019$, $f = 0.35$) and in the third ones ($F(4,308) = 6.59$, $p < 0.001$, $f = 0.29$) with a medium to large and moderate effect sizes[7], respectively. Therefore, the subsequent analyses will be performed separately for each class. Even if the differences between classes were not statistically significant in the second monitoring campaign, they will be also analysed separately in order to compare the results with the other two monitorings.

This preliminary analysis addressed the following **research question:** Can independent variable, i.e. *class*, significantly affect the background noise levels?

3.1.5.1 Effect of SEM device on background noise levels

The following section is aimed at addressing this **research question:** Does SEM device affect the background noise levels generated by pupils?

In Table 15 the averaged overall values, $L_{A90,mean}$, of each class are split in phases 1 and 2 for the three monitoring campaigns, and the significance of the differences between both phases are reported according to data analysis A2. The $L_{A90,mean}$ values of each class are also shown in Figure 24.

In the third monitoring campaign, the averaged $L_{A90,mean}$ values during the phase 2 were significantly lower than phase 1 in classes 1I ($t(76) = 2.264$, $p = 0.026$, $d = 0.52$) and 2N ($U = 232$, $p = 0.012$, $d = 0.72$), with a medium and medium-large effect sizes, respectively. Average decreases of 1.6 dB(A) and 2.4 dB(A) for the classes 1I and 2N were found, respectively.

In the first and second monitoring campaigns, no differences between the two phases were statistically significant according to IS *t*-test or MWU test, as well as the effect sizes generally represents a small effect. In the first monitoring campaign, the presence of the lighting feedback of SEM devices led to a decrease of background noise level in the range 1.4-2.5 dB (A); a single exception to this result was found: in the third-grade class (3B), the average $L_{A90,mean}$ values were approximately the same in both the two phases, on average equal to 48.2 dB(A). Conversely, in the second monitoring campaign, background noise levels in phase 2 were found to be higher than in phase 1, except for the third-grade class (3G)

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[7] Effect sizes for one-way ANOVA were interpreted according to Cohen's *f* labels of small (0.10), medium (0.25), and large (0.40) effects (Cohen, 2013).

where an average decrease by 4.3 dB(A) was found. However, this result was not further investigated due to the small sample size, as shown in Table 15.

Table 15. The average $L_{A90,mean}$ values of phase 1 and phase 2 with the standard deviation reported in the bracket, and the differences in the averaged $L_{A90,mean}$ values between P2 and P1. Two-tailed *p*-values of significance for the differences between P1 and P2 according to IS *t*-test or MWU test and the effect sized values according to Cohen's *d* [8]. Statistically significant differences, with *p*-value < 0.05 are reported in bold.

MC	**ID Class**	**$L_{A90,mean}$**		**$\Delta L_{A90,mean}$**	***p*-value**	***d***
		SEM off Phase 1	**SEM on Phase 2**			
1st	2A	49.3 (2.9)	47.9 (3.3)	-1.4	0.292	0.45
	3B	48.4 (1.5)	48.3 (1.3)	-0.1	0.946	0.05
	4C	51.3 (2.8)	49.8 (3.8)	-1.5	0.114	0.53
	5D	51.9 (4.0)	49.5 (4.7)	-2.5	0.522	0.35
		50.4 (3.0)	49.1 (3.6)	-1.3 (1.0)		
2nd	1E	52.8 (2.8)	53.6 (2.2)	+ 0.8	0.664	0.22
	2F	52.6 (3.6)	53.6 (3.3)	+0.9	0.421	-0.27
	3G	56.5 (5.7)	52.2 (3.8)	-4.3	NA	NA
	4H	55.1 (2.3)	55.7 (2.7)	+0.6	0.673	-0.23
		53.7 (3.7)	53.7 (3.2)	+0.1 (2.5)		
3rd	1I	56.8 (3.3)	55.2 (3.0)	-1.6	**0.026**	0.52
	1L	57.3 (4.0)	56.1 (3.8)	-1.2	0.416	0.31
	2M	55.2 (4.7)	55.4 (3.5)	+0.2	0.978	0.00
	2N	54.7 (4.1)	52.3 (3.6)	-2.4	**0.012**	0.72
	4O	56.0 (3.2)	56.4 (2.9)	+0.4	0.580	-0.14
		55.9 (4.0)	55.0 (3.5)	-0.8 (1.2)		

Note: NA not applicable due to small sample size.

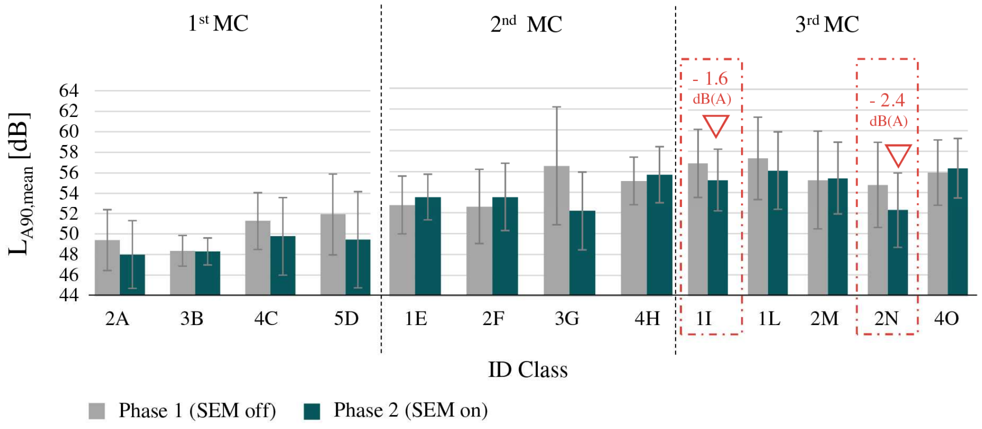

Figure 24. The $L_{A90mean}$ averaged for each class over the three monitoring campaigns related to phase 1 and phase 2. The dotted line rectangle indicates the pair of data samples where a statistically significant difference with *p*-value < 0.05 was found according to IS *t*-test or MWU test.

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[8] Effect sizes for IS *t*-test and MWU test were interpreted according to Cohen's *d* labels of small (0.20), medium (0.50), and large (0.80) effects (Cohen, 2013).

Independently of the two phases, the average background noise levels during traditional lessons ranged from 47.9 to 52.0 dB(A), 52.2 to 56.5 dB(A) and 52.3 to 57.3 dB(A) in first-, second- and third-grades respectively. Thus, lower values of background noise levels were measured for each class during the first monitoring campaign compared to other ones.

The standard deviations in Figure 24 and in Table 15 show the high variation of averaged $L_{A90,mean}$ within each class during the traditional lessons.

The main results are summarised as follows:

- the first-grade class and one second-grade class involved in the third monitoring campaign reported a significant decrease in averaged background noise levels comparing phase 2 and phase 1 ($p < 0.05$), with and without the lighting feedback of SEM devices, respectively.
- The variation between the two phases in terms of averaged background noise levels was not statistically significant in all other classes over the three monitoring campaigns when the fixed factors were not controlled.

3.1.5.2 Effect of fixed factors on background noise levels

This section is aimed at addressing this **research question:** Can independent variables (fixed factors), such as *teacher*, *time-band, number of pupils* and *day of week*, significantly affect the background noise levels in the two lighting feedback conditions?

The two-factors analysis of variance (ANOVA) was performed to estimate the effects of each fixed factor and their interaction with the lighting feedback on dependent variable ($L_{A90,mean}$), as indicated in data analysis A3 in Section 1.3.4. The results were reported in Table 16.

Table 16 shows that a significant main effect of *teacher* exists on the background noise levels for two classes of the second monitoring campaign, that are 2F ($F(1,37) = 18.54$, $p < 0.001$, $f = 0.71$) and 4H ($F(2,14) = 7.84$, $p < 0.01$, $f = 1.3$), and for two classes of the third monitoring campaign, that are 2M ($F(1,69) = 38.61$, $p < 0.001$, $f = 0.75$) and 4O ($F(1,57) = 5.08$, $p < 0.05$, $f = 0.3$). These results indicate that background noise levels were affected differently by teachers when the lighting feedback was ignored. The background levels were not significantly different from phase 1 (SEM off) to phase 2 (SEM on). A significant main effect of lighting feedback was only found in the class 1I ($F(1,70) = 5.84$, $p < 0.05$, $f = 0.29$). This result indicates that background noise levels were affected differently by SEM lighting feedback when teachers were ignored in the evaluation.

Table 16. *P*-values and effect sizes according to Cohen's *f*[9], reported in the bracket, of the four models (M) using two-factors ANOVA. Each model includes the principal effects of one fixed factor, lighting feedback (L) and their interaction on dependent variable ($L_{A90,mean}$). The significant values are reported in bold. The following abbreviations were adopted for fixed factors: T for "teacher"; B for "time-band"; D for "day of week" and P for "number of pupils".

M	***p*-values (Cohen's *f*) for each class**										
	2A	**4C**	**1E**	**2F**	**3G**	**4H**	**1I**	**1L**	**2M**	**2N**	**4O**
T	0.065 (0.44)	0.430 (0.14)	NA	**<0.001** (0.71)	0.263 (0.34)	**0.009** (1.3)	0.678 (0.05)	NA	**<0.001** (0.75)	NA	**0.028** (0.3)
L	0.365 (0.21)	0.177 (0.24)	NA	0.207 (0.21)	0.127 (0.47)	0.786 (0.01)	**0.018** (0.29)	NA	0.779 (0.04)	NA	0.824 (0.03)
T*L	0.248 (0.27)	0.783 (0.05)	NA	0.969 (0.00)	0.617 (0.15)	0.916 (0.13)	0.770 (0.04)	NA	0.756 (0.04)	NA	0.951 (0.0)
B	**0.012** (0.83)	**0.010** (0.58)	0.694 (0.58)	0.255 (0.29)	NA	**0.002** (1.11)	NA	NA	**0.065** (0.27)	0.289 (0.23)	**<0.001** (0.65)
L	0.505 (0.17)	0.160 (0.25)	0.842 (0.05)	0.390 (0.15)	NA	0.821 (0.06)	NA	NA	0.861 (0.00)	0.076 (0.26)	0.324 (0.13)
B*L	0.912 (0.1)	0.771 (0.13)	0.359 (0.28)	0.739 (0.13)	NA	0.948 (0.02)	NA	NA	0.785 (0.08)	0.074 (0.33)	0.907 (0.06)
D	**0.037** (0.85)	NA	0.053 (1.51)	**0.025** (0.57)	NA	NA	0.151 (0.32)	0.458 (0.43)	0.062 (0.36)	NA	0.478 (0.25)
L	0.665 (0.11)	NA	0.763 (0.12)	0.353 (0.16)	NA	NA	0.060 (0.23)	0.845 (0.04)	0.053 (0.23)	NA	0.252 (0.15)
D*L	0.397 (0.46)	NA	0.694 (0.46)	0.721 (0.2)	NA	NA	0.592 (0.2)	0.067 (0.64)	**0.002** (0.51)	NA	0.739 (0.15)
P	0.976 (0.11)	NA	NA	NA	NA	NA	0.405 (0.27)	0.991 (0.0)	NA	NA	0.446 (0.26)
L	0.359 (0.23)	NA	NA	NA	NA	NA	0.084 (0.21)	0.405 (0.20)	NA	NA	0.446 (0.26)
P*L	0.444 (0.19)	NA	NA	NA	NA	NA	0.253 (0.25)	0.706 (0.09)	NA	NA	0.212 (0.29)

Note: NA not applicable due to small sample size and the violation of ANOVA assumptions, respectively. The classes 3B and 5D were excluded due to the small sample size in each model.

A focus on the significant results is shown in Figure 25 and Figure 26 to better understand the differences between teachers in the two conditions of the lighting feedback. Average background noise levels were different between teachers in both the two conditions of SEM devices, except for two teachers (O and P) in the class 4H where non-parallel lines indicate some degree of interaction, i.e. the differences between teachers varied depending on the conditions of the lighting feedback. However, this interaction is not significant. Figure 26 shows that dependent variable ($L_{A90,mean}$) significantly decrease in phase 2 compared to phase 1 for both teachers.

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[9] Effect sizes for two-factors ANOVA were interpreted according to Cohen's (1969 p.348) labels of small (0.10), medium (0.25), and large (0.40) effects.

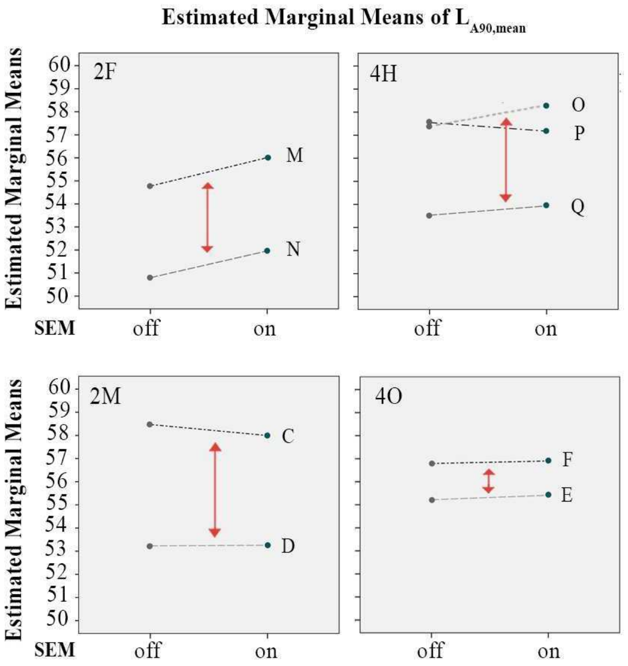

Figure 25. The differences between teachers on the background noise levels according to the two conditions of the lighting feedback of SEM for the four classes where *teacher* is statistically significant fixed factor on dependent variable ($L_{A90,mean}$). ID teacher is indicated with capital letters in the graphs.

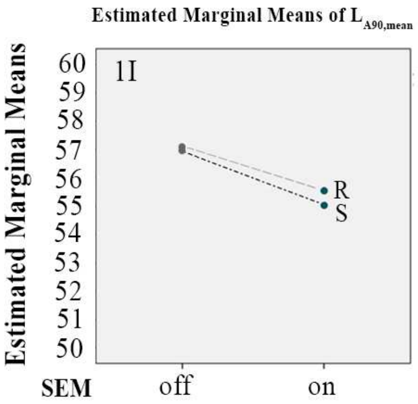

Figure 26. The difference between teachers on the background noise levels according to the two conditions of SEM for the class 1I where a significant main effect of SEM lighting feedback on dependent variable ($L_{A90,mean}$) was found. ID teacher is indicated with capital letters in the graph.

Table 16 shows that a main significant effect of the *time band* on the background noise levels exists for the classes 2A ($F(2,17) = 5.84$, $p < 0.05$, $f = 0.83$) and 4C ($F(2,32) = 5.30$, $p < 0.05$, $f = 0.58$) of the first monitoring. In addition, *time-band* of the working period significantly affects the background noise levels of the fourth-grade classes of the second and third monitoring campaigns, respectively, that are 4H ($F(1,12) = 14.91$, $p < 0.0$, $f = 1.11$) and 4O ($F(2,62) = 12.96$, $p < 0.001$, $f = 0.65$). These results indicate that background noise levels are affected differently by time-band of the working period. In the other classes the main effect of *time-band* is not significant; however, it did represent a large and medium-sized effect. Dependent variable ($L_{A90,mean}$) was not significantly different between phase 1

(SEM off) and phase 2 (SEM on) for all classes when time-band is considered as fixed factor in the model.

A focus on the significant results is shown in Figure 27: the differences due to the *time-band* are plotted against the two conditions of the lighting feedback. The average background noise levels were different between the three time-bands of the working day in the two conditions of SEM devices, except between the two morning periods before (M1) and after (M2) recreation time in the class 4C, where non-parallel lines indicate some degree of interaction, i.e. the differences between the two morning periods varied depending on the conditions of the lighting feedback. However, this interaction is not significant. Increased average $L_{A90,mean}$ values can be seen over the three time-bands of the working day, that are morning period before (M1) and after (M2) recreation time and afternoon period after lunch break (A3), respectively.

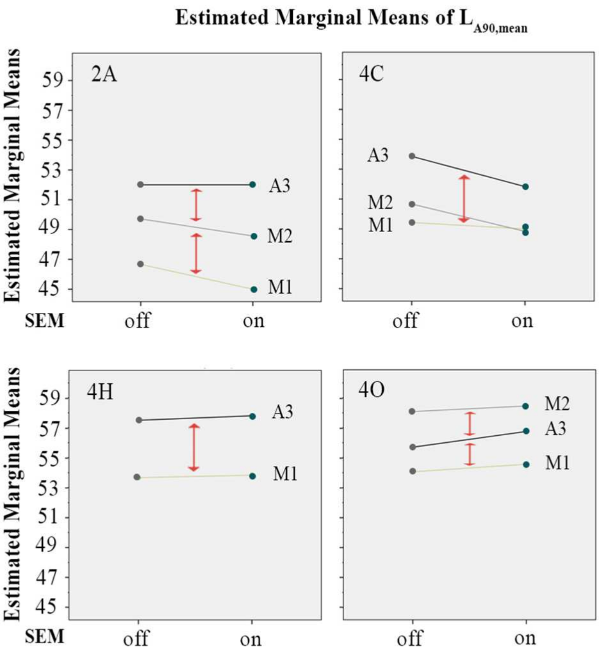

Figure 27. The differences between the three time-bands of the working day on the background noise levels according to the two conditions of the lighting feedback of SEM for the four classes where *time-band* is statistically significant fixed factor on dependent variable ($L_{A90,mean}$). The ID codes of the three time-bands are indicated with capital letters in the graphs.

The fixed factor *day of week* has a significant effect on background noise levels when the lighting feedback was ignored in the classes 2A ($F(3,25) = 3.64$, $p < 0.05$, $f = 0.85$) and 2F ($F(3,33) = 3.6$, $p < 0.05$, $f = 0.57$) of the first and second monitoring campaigns (Table 16). In addition, a significant interaction between the *day of week* and the lighting feedback of SEM on the background noise levels was found in the class 2M ($F(4,14) = 4.70$, $p < 0.05$, $f = 0.51$). This result indicates that the effect of *day of week* on dependent variable ($L_{A90,mean}$) was different when the two lighting feedback conditions were compared.

A focus on the significant results is shown in Figure 28: the differences due to the *day of week* are plotted against the two conditions of the lighting feedback. The difference between Tuesday and the other days of week was maintained over the two conditions of the lighting feedback in the class 2A; conversely, an interaction was found between the other days and SEM lighting feedback. However, the degree of this interaction is not significant. The significant interaction between lines in the class 2M reflects the different effect of *day of week* on dependent variable ($L_{A90,mean}$) when the lighting feedback was switched off or switched on.

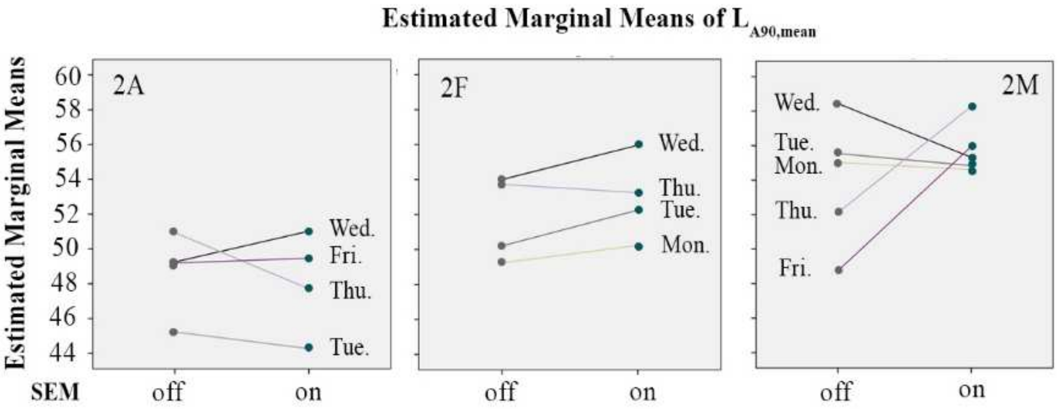

Figure 28. The differences between the day of week on the background noise levels according to the two conditions of the lighting feedback of SEM devices for the three classes where *day of week* or its interaction with LF is statistically significant. The days are indicated with the first letters of name in the graphs.

Table 16 also shows that the *number of pupils* is not a significant factor related to background noise levels. This result may be caused by the little variability in the number of pupils over the days, as suggested by the maximum range of variability indicated in Table 9 (Section 3.1.2.1.) and the absence of results of factorial ANOVA in some classes (Table 16).

In some classes (2A and 1E) the main effects of *teacher*, *time-band* and *day of week* were not significant; however, it did represent a large-sized effect. These results could be caused by the smaller sample size, between 16 and 23 observations, compared to the other classes since the effect size is intrinsically linked to the number of observations.

On data samples where the assumptions of ANOVA analysis were violated, MWU test and KW test were performed separately for the two conditions of the lighting feedback. A significant difference between teachers was obtained in the class 1E when the lighting feedback was switched on according to KW test ($\chi2(2) = 6.385$, $p = 0.041$, d[10] $= 2.59$). In the class 1L, a significant difference between the two *time-bands* on background noise levels was only found in phase 1 according to MWU test ($U = 2.00$, $z = -2.71$, $p < 0.05$, $d = 2.29$), with lower $L_{A90,mean}$ values in

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[10] Estimates of effect sizes was manually determined through the Cohen's d equation based on the transformation from partial Eta-squared to d according to (Cohen, 2013; Lenhard W. and Lenhard A., 2016)

M1 period (M = 55.3 dB(A), Min = 47.6 dB(A), Max = 58.9 dB(A), s.d.= 3.9 dB(A)) compared to M2 period (M = 60.4 dB(A), Min = 58.7 dB(A), Max = 61.5 dB(A), s.d.= 1.0 dB(A)). The afternoon period (A3) was excluded due to missing data.

Figure 29 shows that some degree of interaction was found between the effect of fixed factors and the effect of the lighting feedback on dependent variable ($L_{A90,mean}$) in some classes. However, the degree of interaction is not significant, as indicated in Table 16. Indeed, the significance of the interaction depends how non-parallel the lines are and the presence of crossing lines don't always reflect a significant interaction (Field, 2018). Given the exploratory nature of this study, it was decided to report the non-significant interaction graphs to show a trend that will have to be further investigated in future monitoring campaigns.

The main results are summarised as follows:

- *teacher* and *time-band* of the working day were found to be significant fixed factors on the background noise levels in a large number of classes, independently of the presence of SEM devices.
- A significant increasing trend of average $L_{A90,mean}$ values was found over the three time-bands (morning before/after recreation time, and afternoon).
- The *day of week* was found to be a less influent fixed factor on background noise levels on the whole sample of classes.
- *Number of pupils* was not a significant factor in terms of variation of background noise levels, however this result may be caused by the little variability in the number of pupils over the days.

Moreover, some degree of interactions emerged between the effect of the fixed factors and the effect of the lighting feedback on dependent variable ($L_{A90,mean}$), even if only one interaction between *day of week* and lighting feedback was statistically significant. The effect of lighting feedback was not significant on background noise levels, except in the class 1I in the model 1. Overall, the estimation of the effects of the fixed factors and their interaction with SEM device on dependent variable ($L_{A90,mean}$) should be carried out to have a deeper evaluation of the effect of the lighting feedback on background noise levels in classrooms.

As these results can in part confirm the literature review (Shield and Dockrell, 2004; Astolfi et al., 2012; Massonnié et al., 2019), the subsequent analyses were carried out controlling the fixed factors, i.e. the latter will be the same in the comparison between background noise levels of phase 1 and phase 2, in contrast to the previous studies on the benefits of the lighting feedback systems in classrooms (Prakash et al., 2011; Van Tonder et al., 2016).

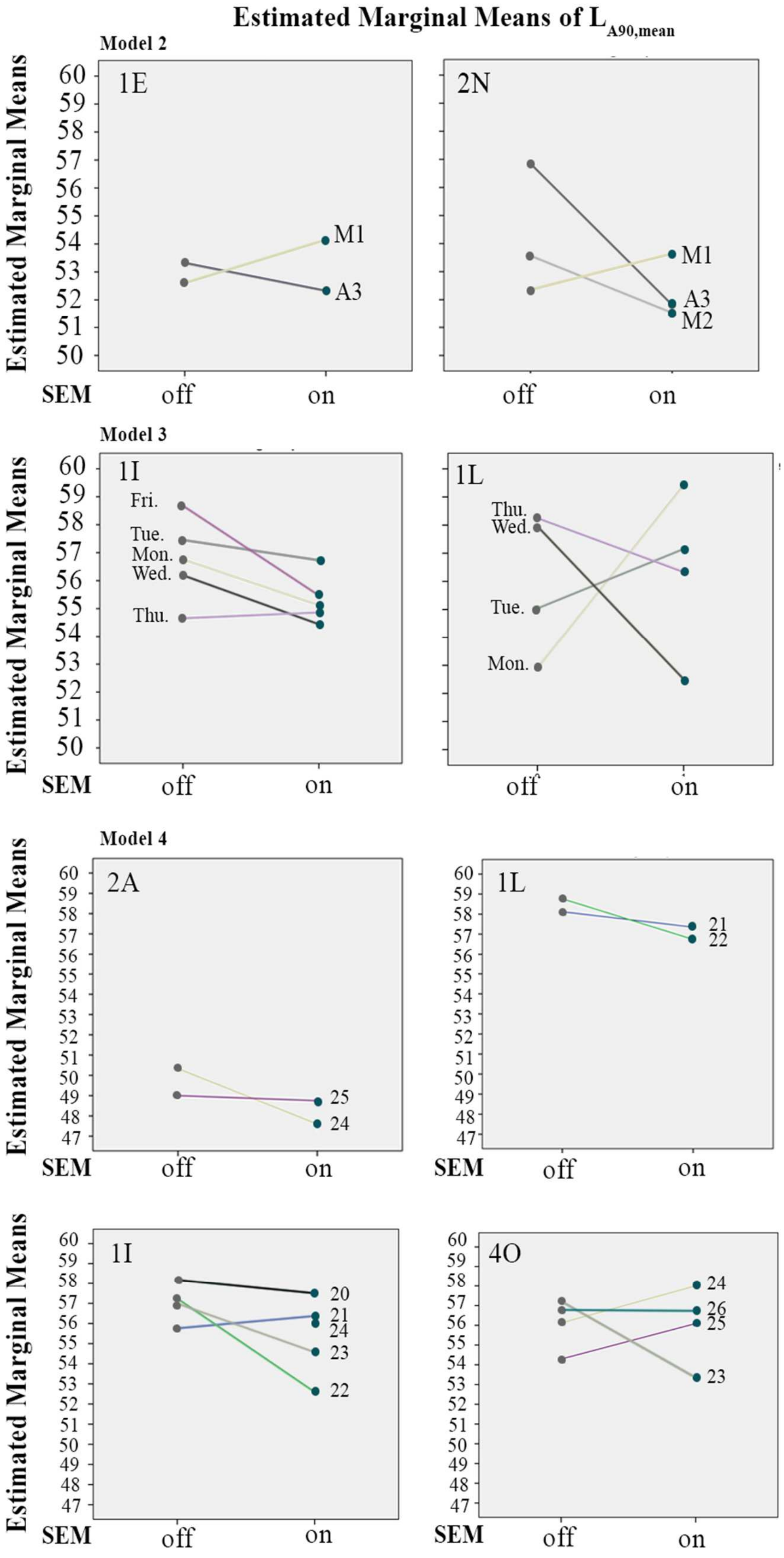

Figure 29. Graphs of the interactions of the effect of *time-band* (Model 2), *day of week* (Model 3) and *number of pupils* (Model 4) and the effect of lighting feedback on background noise levels. The interactions are not statistically significant.

3.1.5.3 Effect of SEM device on background noise levels controlling the fixed factors

The following section is aimed at addressing this **research question:** Does SEM device affect the background noise levels generated by pupils?

Table 17 shows that the final sample of L_{A90} occurrences distributions related to phases 1 and 2 consists of 547 cases, according to the statistical analysis A4, in which the significance of the differences in L_{A90} occurrences distributions between phase 1 and phase 2 was investigated controlling the fixed factors. A significant decrease of background noise levels in phase 2 was obtained for 278 cases according to the right-tailed MWU test (p-value < 0.05 with 95% confidence interval). These cases based on pairs of independent L_{A90} occurrences distributions related to a day of P1 and P2 are indicated by the term **"improvement"** in the present dissertation, since a significant reduction of background noise levels was found when the lighting feedback was switched on. In the previous section of data analysis, Figure 22 shows an example of a pair of independent L_{A90} occurrences distributions identified as a background noise improvement. In the other 269 cases, background noise levels increased or did not significantly decrease in phase 2. Several reasons may be hypothesised for this result: for example pupils paid smaller attention towards the lighting feedback because the activities required more interaction between them and teachers. Moreover, the engagement of teachers aimed at motivating pupils to follow the lighting feedback was lower. These cases are indicated by the term **"no improvement"**.

Table 17. The number of statistically significant "improvements" (I) in relation to the total pair of independent L_{A90} occurrences distributions of phase 1 and phase 2 (Total cases) and the percentage of "improvements" for each class, each monitoring campaign and the whole sample.

MC	ID Class	I/Total cases	Percentage of I
1st	2A	10/15	67%
	3B	3/9	33%
	4C	12/19	65%
	5D	3/7	59%
		28/50	**56%**
2nd	1E	2/10	20%
	2F	6/25	24%
	3G	5/10	58%
	4H	5/12	42%
		18/57	**32%**
3rd	1I	65/103	64%
	1L	15/26	59%
	2M	71/142	51%
	2N	45/75	56%
	4O	36/94	41%
		232/440	**53%**
		278/547	**51%**

Table 17 shows that the high comparable percentages of "improvements" were found in the first and third monitoring campaigns (53-56%). Conversely, a strongly lower improvement rate (32%) was obtained in the second monitoring campaign. No trends can be identified based on grade class, suggesting that differences between classes were independent from pupils' age. A graphical representation of these results is presented in Figure 30.

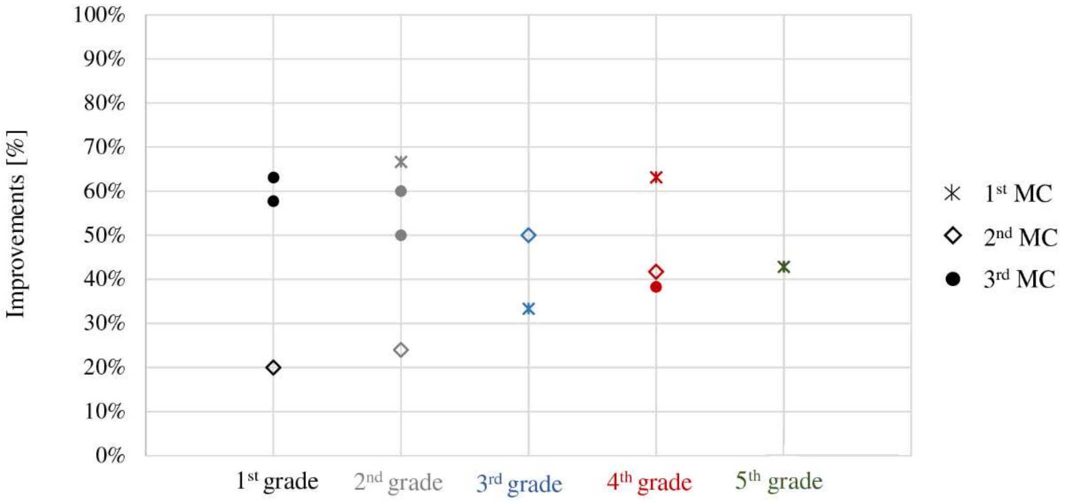

Figure 30. The percentages of "improvements" split into grade class separately for each monitoring campaign. The different colours indicate the grade class, while the different symbols represent the three monitoring campaigns.

Table 18 shows the averaged differences between $L_{A90,mean}$ values in phases 2 and 1 for each class. The values are reported separately for "improvement" and "no improvement" groups. The significance of such differences is also reported according to the Wilcoxon signed-rank test (p-value < 0.05 with 95% confidence interval), as indicated in data analysis A5 (Section 1.3.4).

The average decrease of $L_{A90,mean}$ values when the lighting feedback is switched on is about 3.2, 2.2 and 3.3 dB in the first, second and third monitoring campaigns, respectively. While, the average increase of $L_{A90,mean}$ values in phase 2 is about 1.6, 1.9 and 2.5 dB in the first, second and third monitoring campaigns, respectively.

The analysis is now focused on the comparison between the two groups: "improvements" and "no improvements".

Figure 31 shows the distribution of $L_{A90,mean}$ values for each class related to phase 1. It can be noted, in the absence of the lighting feedback, the typical background noise levels were higher in the "improvement" group compared to "no improvement" group. This result highlights that the significant decrease of background noise levels, in the presence of the lighting feedback (phase 2), emerged only when the starting noise conditions were worse.

Table 18. The average $L_{A90,mean}$ values of phase 1 and phase 2 related to “improvement” (I) and “no improvement” (NI) groups, respectively, with standard deviation reported in brackets, and the differences in the averaged $L_{A90,mean}$ values between P2 and P1. Two-tailed *p*-values of significance for the differences between the two phases according to Wilcoxon signed-rank test, and the effect size according to Cohen’s *d* [11] are also stated. Statistically significant differences are reported in bold.

MC	ID Class	Group	$L_{A90,mean}$		$\Delta L_{A90,mean}$	*p*-value	*d*
			SEM off Phase 1	**SEM on Phase 2**			
1st	2A	I (10)	50.8 (2.6)	47.6 (2.9)	-3.2	**0.005**	1.61
		NI (5)	47.9 (2.6)	49.3 (3.1)	1.4	NA	NA
	3B	I (3)	49.3 (0.7)	46.7 (0.6)	-2.6	NA	NA
		NI (6)	47.9 (1.6)	48.9 (1.0)	1.0	0.116	-1.02
	4C	I (12)	50.8 (1.9)	47.5 (2.0)	-3.3	**0.001**	1.60
		NI (7)	50.0 (1.5)	52.7 (3.8)	2.6	0.063	-1.15
	5D	I (3)	54.1 (4.8)	51.1 (1.9)	-2.9	NA	NA
		NI (4)	49.7 (2.0)	50.6 (2.2)	0.9	NA	NA
		Average I	51.0 (2.6)	47.9 (2.5)	-3.2 (0.3)		
		Average NI	48.9 (2.0)	50.5 (3.1)	1.6 (0.8)		
2nd	1E	I (2)	54.6 (0.1)	53.1 (1.4)	-1.5	NA	NA
		NI (8)	52.3(3.0)	53.6 (2.4)	1.3	**0.036**	-1.23
	2F	I (6)	53.4 (4.2)	52.0 (4.1)	-1.4	**0.027**	1.65
		NI (19)	51.6 (2.1)	53.5 (2.2)	1.8	**< 0.001**	-1.50
	3G	I (5)	57.7 (5.2)	53.3 (1.2)	-4.4	NA	NA
		NI (5)	49.3 (0.4)	53.0 (1.6)	3.8	NA	NA
	4H	I (5)	57.4 (0.1)	55.1 (1.9)	-2.3	NA	NA
		NI (7)	54.5 (2.9)	56.3 (3.0)	1.8	0.128	-0.89
		Average I	55.6 (4.1)	53.4 (2.9)	-2.2 (1.4)		
		Average NI	52.1 (2.7)	54.0 (2.5)	1.9 (1.1)		
3rd	1I	I (65)	57.7 (2.4)	54.3 (2.7)	-3.4	**< 0.001**	1.56
		NI (38)	54.5 (2.9)	56.3 (3.0)	1.8	**< 0.001**	-1.10
	1L	I (15)	58.4 (2.5)	54.4 (3.0)	-4.0	**0.001**	1.59
		NI (11)	53.7(4.5)	58.3 (2.4)	4.6	**0.004**	-1.53
	2M	I (71)	58.0 (3.2)	54.5 (2.3)	-3.5	**< 0.001**	1.56
		NI (71)	53.4 (4.1)	55.9 (3.8)	2.6	**< 0.001**	-1.42
	2N	I (45)	53.6 (2.6)	50.1 (1.0)	-3.6	**< 0.001**	1.55
		NI (30)	51.3 (2.5)	52.9 (3.6)	1.6	**0.001**	-0.93
	4O	I (36)	57.5 (2.4)	54.6 (2.0)	-2.9	**< 0.001**	1.46
		NI (58)	54.7 (2.7)	57.0 (2.7)	2.2	**< 0.001**	-1.11
		Average I	57.1 (1.6)	53.8 (1.9)	-3.3 (0.4)		
		Average NI	53.7 (1.6)	56.2 (2.1)	2.5 (1.2)		

Note: NA not applicable due to small sample size. The numerosity of the data sample was indicated in the bracket in column “Groups”.

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[11] Effect sizes for IS *t*-test and MWU test were interpreted according to Cohen’s *d* labels of small (0.20), medium (0.50), and large (0.80) effects (Cohen, 2013).

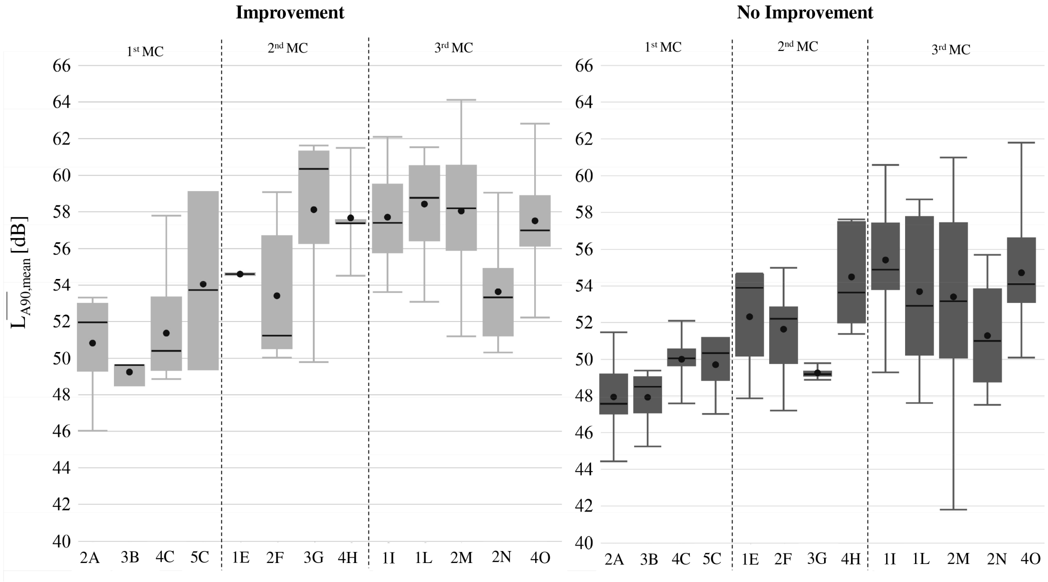

Figure 31. Boxplots on the distribution of $L_{A90,mean}$ values for each class related to phase 1 split into "improvement" and "no improvement" groups. The boxes represent the interquartile (IQ) range, which contains the middle 50% of the records. The whiskers lines that extend from the top and bottom of the box show the top and bottom 25% of score (approximately). The thick line across the box and the dot indicates the median and mean, respectively.

Table 18 shows that the significance of the differences between both phases emerged in the two groups for the majority of the classes. However, the decrease of background noise levels was higher compared to the increase of background noise levels when the lighting feedback was switched on, except in the class 2F and 1L. A graphical representation of these results is presented in Figure 32.

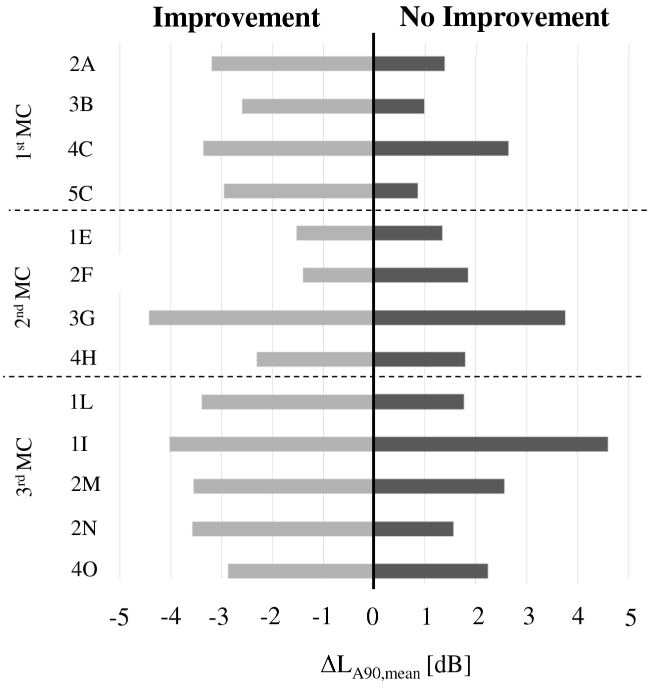

Figure 32. The differences in the averaged $L_{A90,mean}$ values between phase 2 (SEM on) and phase 1 (SEM off) divided into the two groups: "improvement" and "no improvement".

Finally, the average $L_{A90,mean}$ values of the “no improvement” group in phase 2 did not exceed the higher average $L_{A90,mean}$ values of the “improvement” group measured in phase 1 in the three monitoring campaigns (Table 18). Indeed, the average $L_{A90,mean}$ values were 50.6, 54.0 and 56.2 dB in phase 2 for “no improvement” group in first, second and third monitoring campaigns, respectively. Conversely, the respective average $L_{A90,mean}$ values were 54.1, 55.6 and 57.1 dB in phase 1 for “improvement” group. Therefore, even when despite the presence of the lighting feedback, the background noise level has increased, the levels attained were lower than the starting background noise levels (phase 1) observed in the cases in which the feedback was found effective and the starting noise conditions were worse.

The analysis is now focused on the 278 improvement pairs of independent L_{A90} occurrences distributions where the effect of the lighting feedback system is assumed to be effective in terms of noise reduction. The reported effect sizes represent a large effect in the differences of averaged $L_{A90,mean}$ values between phase 1 and phase 2 in all classes in which the significance of the differences was estimated.

In the third monitoring campaign, lower background noise levels were found in the class 2N in both the two phases. By excluding these values, identified as outliers according to boxplots in Figure 33, the averaged background noise levels are equal to 57.5 dB(A) and to 54.3 dB(A) in phases 1 and 2, respectively, with low variability in the values (P1:s.d = 0.4 dB(A), P2:s.d = 0.2 dB(A)). In the second monitoring campaign, similar averaged $L_{A90,mean}$ values of 55.6 dB and 53.4 dB were obtained in phases 1 and 2, but higher variability was found (P1:s.d = 4.1 dB(A), P2:s.d = 2.9 dB(A)). Conversely, the averaged values of $L_{A90,mean}$ values were lower in the first monitoring campaign: 51 dB(A) and 47.9 dB(A) were found in phase 1 and in phase 2, respectively, with medium-large variability (P1:s.d = 2.6 dB(A), P2:s.d = 2.5 dB(A)).

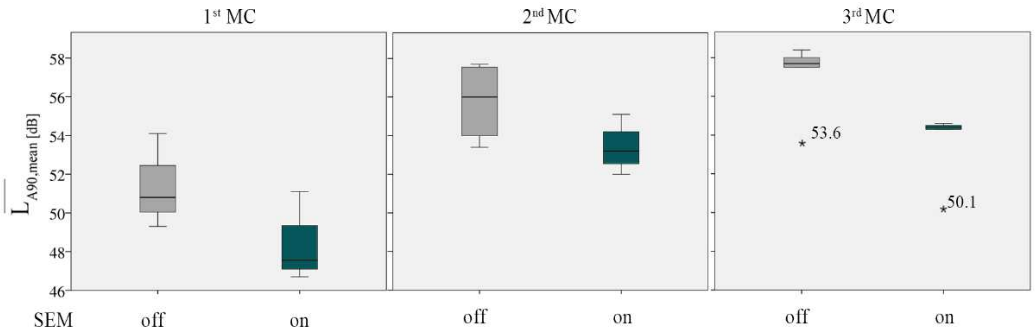

Figure 33. Boxplots of the averaged $L_{A90,mean}$ values of phase 1 (grey colour) and phase 2 (green colour) related to significant improvements for each monitoring campaign.

The main results are summarised as follows:

- the average background noise levels during traditional lessons ranged from 48.0 dB(A) to 51.9 dB(A), 52.2 dB(A) to 56.5 dB(A) and 52.3 dB(A) to 57.3 dB(A) in the first, second and third school year respectively.
- A significant decrease of background noise levels was found for a total of 51% pairs of independent L_{A90} occurrences distributions when the visual feedback of the noise monitoring system was switched on.
- The activation of the lighting feedback led to an average decrease of 3.2 dB(A), 2.2 dB(A) and 3.3 dB(A) in the first, second and third monitoring campaigns, respectively. These decreases emerged when the starting noise conditions were worse, i.e. the background noise levels were highest in the absence of the lighting feedback.
- The background noise levels increased or did not significantly decrease in the presence of the lighting feedback for a total of 49% pairs of independent L_{A90} occurrences distributions.
- The average increase of $L_{A90,mean}$ values in the presence of the lighting feedback, was about 1.6 dB, 1.9 dB and 2.5 dB in the first second and third monitoring campaigns, respectively. These increases were lower compared to the decreases of background noise levels when the lighting feedback was switched on.
- The effect sizes confirmed the large decrease in average background noise levels when the lighting feedback of SEM is switched on.
- The effect of SEM devices in terms of reduction on average $L_{A90,mean}$ was higher in the first monitoring campaign, follow by the third monitoring ones, comparing the increases and decreases of the background noise levels.

3.1.5.4 Effect of motivational methods on background noise levels

This section is aimed at addressing this **research question:** Can the motivational methods, based on constant feedback and/or game-based challenge, encourage pupils towards a long-term behavioural change?

The effect of the motivational methods was evaluated on the average $L_{A90,mean}$ values between of phase 2 by considering the two groups: “improvement” and “no improvement”. The differences were grouped according to the division of P2 in two or three groups, as identified in the description of data analysis A6 (Section 3.1.4).

Even if the motivational method was not applied during the **first monitoring campaign**, the outcomes are reported as a reference condition to later assess the change in background noise levels when the motivational methods were introduced. Since the first monitoring campaign had different durations (3 weeks in 4C and 5D; 4 weeks in 2A and 3B), the background noise levels of phase 2 have been weekly split.

Table 19 highlights that the higher numbers of improvements were found in the first week in all classes. The average $L_{A90,mean}$ values of phase 1 and phase 2 were plotted over the weeks for “improvement” and “no improvement” groups in Figure 34. The classes 3B and 5D were excluded due to the high number of missing values.

Table 19. The average $L_{90,mean}$ values of phase 1 and phase 2 related to “improvement” and “no improvement” groups. The values are subdivided into four or three weeks (W) of P2 of the first monitoring campaign with the standard deviations reported in the brackets.

ID Class	**Week**	**Improvement**			**No improvement**		
			$L_{A90,mean}$			$L_{A90,mean}$	
		Perc.	**SEM off Phase 1**	**SEM on Phase 2**	**Perc.**	**SEM off Phase 1**	**SEM on Phase 2**
2A	W1(1)	100%	49.2 (-)	47.0 (-)	0%	NA	NA
	W2(5)	80%	49.7 (3.5)	46.6 (4.2)	20%	47.0 (-)	50.0 (-)
	W3(4)	50%	52.6 (-)	50.4 (-)	50%	49.5 (2.8)	50.0 (2.8)
	W4(5)	59%	51.7 (1.8)	47.2 (0.4)	41%	46.8 (3.4)	48.2 (5.2)
3B	W1(2)	100%	49.1 (0.8)	46.3 (0.3)	0	NA	NA
	W2(2)	50%	49.6 (-)	47.3 (-)	50%	48.5 (-)	47.3 (-)
	W3(1)	0	NA	NA	100%	49.2 (-)	49.3 (-)
	W4(4)	0	NA	NA	100%	47.4 (1.9)	49.2 (0.9)
4C	W1(6)	86%	52.9 (1.1)	48.6 (1.3)	14%	50.6 (-)	50.4 (-)
	W2(9)	56%	47.7 (1.8)	47.8 (2.5)	44%	49.8 (1.8)	50.9 (2.7)
	W3(4)	50%	50.2 (0.6)	46.2 (3.4)	50%	54.1 (5.2)	57.2 (2.1)
5D	W1(0)	0	NA	NA	0	NA	NA
	W2(6)	50%	54.1 (4.8)	51.2 (-)	50%	49.2 (2.1)	49.8 (1.9)
	W3(1)	0	NA	NA	100%	51.2 (-)	52.9 (-)

Note: NA not applicable due to the missing values in the group. The numerosity of the whole sample was indicated in the brakects in the column “Week”.

Figure 34 shows that the background noise levels were not significantly lower in the first week compared to the other weeks in the “improvement”, contrary to expectations. The researchers’ hypothesis was based on the premise that the novelty effect of the lighting feedback would have led to a higher decrease of background noise levels in the first week of phase 2, as resulting of more interest of pupils on SEM device. Conversely a decreasing trend of the average $L_{90,mean}$ values over the entire phase 2 was found in the class 4C, despite the motivational method was not used in the first monitoring campaign. A decrease trend was found over the weeks in the “no improvement” group in the class 2A, while an opposite result emerged in the class 4C. Overall, these findings suffer of one important limitation related to the small samples size. Therefore, the aforementioned considerations must be interpreted with caution.

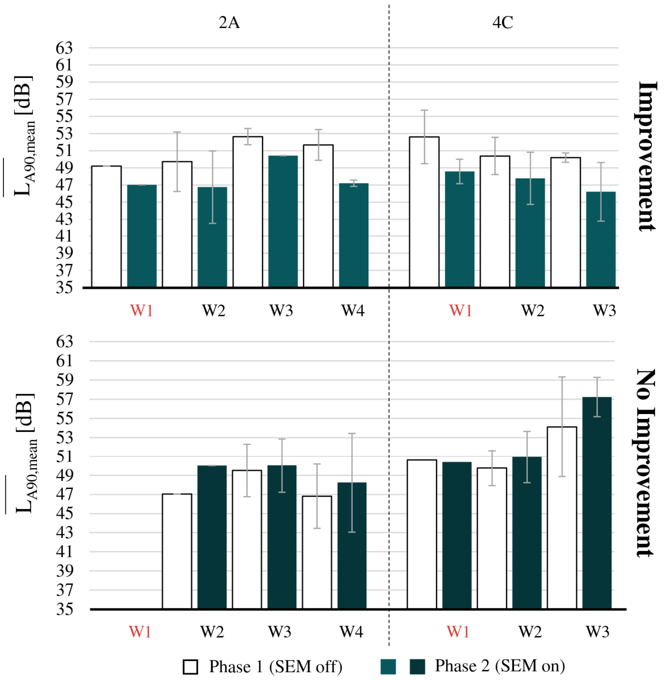

Figure 34. The average $L_{90,mean}$ values of phase 1 and phase 2 over the four or three weeks (W) of P2, by considering the "improvement" and "no improvement" group. The bars of standard deviations are indicated. The $L_{A90,mean}$ values related to P1 are also reported as a reference.

The results on the effects of the motivational methods introduced in the second and third monitoring campaigns are reported below.

In the **second monitoring campaign**, the percentages of improvements in Table 20 show that the significant decreases of background noise levels in phase 2 compared to phase 1 were mainly concentrated in the first period of P2, except in the class 3G in which the number of improvements were the same in both periods.

Table 20. The average $L_{90,mean}$ values of phase 1 and phase 2 related to "improvement" and "no improvement" groups. The $L_{90,mean}$ values are subdivided into first (FP) and last (LP) period of P2 of the second monitoring campaign with the standard deviations reported in the brackets. The percentage (Perc.) of "improvements" and "no improvements" are also indicated over the two periods.

ID Class	**Period**	**Improvement**			**No improvement**		
			$L_{A90,mean}$			$L_{A90,mean}$	
		Perc.	**SEM off Phase 1**	**SEM on Phase 2**	**Perc.**	**SEM off Phase 1**	**SEM on Phase 2**
1E	FP(7)	29%	54.6 (0.1)	53.1 (1.4)	71%	52.2 (2.8)	53.2 (2.9)
	LP(3)	0%	NA	NA	100%	52.4 (3.9)	54.4 (1.6)
2F	FP(6)	50%	50.8 (0.8)	49.7 (0.6)	50%	52.3 (1.3)	53.2 (1.6)
	LP(19)	16%	56.0 (4.8)	54.4 (4.9)	84%	52.0 (2.7)	54.4 (3.2)
3G	FP(4)	50%	55.1 (3.0)	51.7 (4.0)	50%	49.5 (0.4)	52.4 (1.2)
	LP(6)	50%	59.4 (3.9)	53.3 (1.2)	50%	51.0 (3.4)	53.4 (1.9)
4H	FP(7)	57%	57.7 (2.9)	54.8 (2.1)	43%	56.3 (2.3)	56.4 (1.9)
	LP(5)	20%	57.6 (-)	56.4 (-)	80%	53.2 (2.8)	56.2 (4.0)

Note: NA not applicable due to the missing values in the group. The numerosity of the whole sample is reported in the brackets in the column "Period".

The analysis is now focused on the average $L_{A90,mean}$ values over the two periods by considering the "improvement" and "no improvement" groups (Figure 35). The class 1E was excluded by the description of these results due to missing data. The averaged $L_{A90,mean}$ values were lower in the first period compared to the last one in all classes in the "improvement" group. The same trend was found in the "no improvement" group, except in the class 4H in which the background noise levels were stable over time. These results show that the background noise levels continue to increase over the period 2 of the second monitoring campaign, despite the goal of motivational method, i.e. the promotion of a constant interaction between pupils and SEM and, consequently, the fulfilment of low background noise levels over the entire period of monitoring. It is important to note that the standard deviation bars overlap, indicating that the differences between the two periods could be not significant. Thus, there was only a tendency towards higher background noise levels after the first period of the monitoring suggesting the difficulty to properly evaluate the effect of the motivational method on the fulfilment of a long-term behavioural change.

Based on teachers' opinions collected at the end of the monitoring campaign, the mobile app was used when pupils asked them to show the trend of total number of green, yellow and red light colours obtained during lessons. However, a clear interpretation of the effect of motivational methods would have been obtained through the administration of a questionnaire at the end of the monitoring campaign.

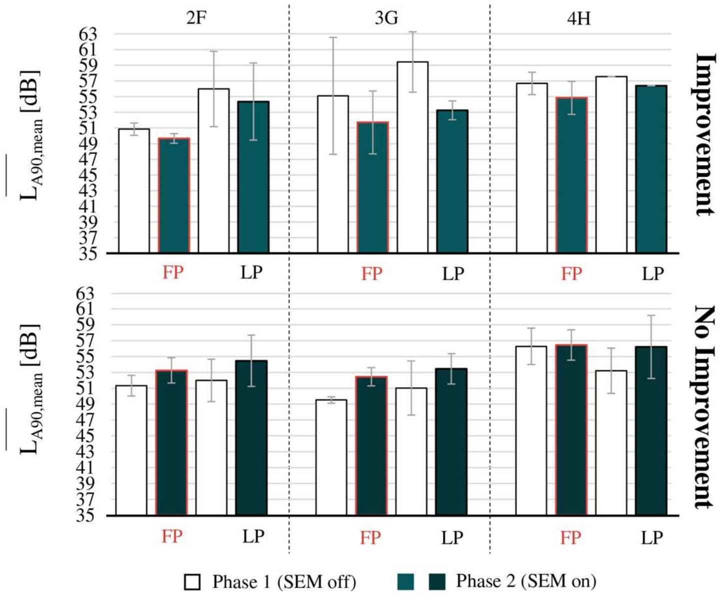

Figure 35. The average differences of $L_{A90,mean}$ values between phase 2 and phases 1 over the first (FP) and last (LP) period of P2, by considering the "improvement" and "no improvement" groups. The bars of standard deviations are indicated. The $L_{A90,mean}$ values related to P1 are also reported as a reference.

The results related to the **third monitoring campaign** are reported in Table 21. A higher percentage of improvements was found in the first period of phase 2 only in the class 4O (42%). This result highlights that the cases of improvements were split in the three periods of P2 for the other classes.

Table 21. The average $L_{90,mean}$ values of phase 1 and phase 2 related to "improvement" and "no improvement" groups. The values are subdivided into first (FP), middle (MP) and last (LP) period of P2 of the third monitoring campaign with the standard deviations reported in the brackets. The percentage (Perc.) of "improvements" and "no improvements" are also indicated over the two periods.

ID Class	Period	Improvement			No improvement		
		Perc.	$L_{A90,mean}$		Perc.	$L_{A90,mean}$	
			SEM off Phase 1	SEM on Phase 2		SEM off Phase 1	SEM on Phase 2
1I*	FP(35)	58%	58.1 (2.2)	55.4 (2.6)	42%	55.8 (3.3)	57.7 (2.0)
	MP(38)	56%	58.3 (2.6)	54.7 (2.1)	44%	54.3 (3.1)	56.8 (2.5)
	LP(24)	83%	56.6 (1.8)	52.7 (2.8)	17%	50.1 (3.6)	54.8 (1.3)
1L	FP(12)	67%	58.9 (2.4)	55.4 (3.1)	33%	53.0 (4.5)	58.9 (3.6)
	MP(8)	38%	60.0 (1.3)	54.5 (2.6)	62%	54.8 (4.3)	57.8 (1.7)
	LP(6)	67%	56.2 (2.4)	52.3 (2.8)	33%	53.1 (7.8)	58.1 (2.4)
2M	FP(42)	40%	57.3 (3.6)	53.5 (2.0)	60%	52.7 (4.7)	55.6 (4.1)
	MP(69)	49%	58.5 (3.1)	54.8 (2.2)	51%	53.7 (3.7)	56.2 (3.7)
	LP(15)	76%	58.4 (2.4)	54.7 (0.8)	24%	54.4 (3.2)	55.5 (2.8)
2N	FP(20)	60%	53.4 (3.4)	50.6 (1.5)	40%	51.4 (2.6)	52.1 (4.1)
	MP(32)	56%	54.4 (3.2)	50.0 (2.8)	44%	50.9 (2.6)	52.9 (3.2)
	LP(15)	69%	55.1 (3.8)	50.7 (1.5)	31%	52.3 (1.7)	54.1 (4.2)
4O*	FP(31)	42%	58.0 (2.8)	55.2 (1.4)	58%	54.9 (2.1)	56.5 (1.9)
	MP(40)	35%	57.1 (1.1)	54.8 (2.8)	65%	54.5 (2.7)	56.8 (2.4)
	LP(16)	39%	56.4 (0.6)	53.4 (0.9)	61%	55.1 (3.5)	58.3 (4.1)

Note: The numerosity of the whole sample is reported in the brackets in the column "Period". One-way ANOVA and MWU test significance across the two periods of monitoring (p-value < 0.05) is indicated with an asterisk (*) near the class.

Moreover, the average $L_{A90,mean}$ values of P2 related to the "improvement" group show that a decreasing trend besides the first period of P2 emerged for the classes 1I, 1L and 4O, while an increasing trend was obtained in the class 2M (Figure 36). In the class 1I background noise levels also tend to decrease over the period 2 in the "no improvement" group, indicating that the background noise levels were lower in the middle and last period even if an increase between P2 and P1 were found. This trend could be caused by the effective of the motivational method. However, it is only a consideration since a same trend did not emerge in the other classes, in which the background noise levels were stable or were increased over P2.

A statistically significant effect of the fixed factor *period of monitoring* was found in the class 1I according to one-way ANOVA analysis ($F(2,62) = 6.68$, $p = 0.002$, $f = 1.21$). A Tukey post hoc test revealed that the statistically significant differences in the averaged $L_{A90,mean}$ values exist between the first and the last periods and between the middle and last periods in the improvement group. Planned contrasts revealed that background noise levels significantly decreased in the last period compared to first period ($t(39) = 3.259$, $p = 0.002$, $d = 1.02$) and middle period ($t(42) = 2.705$, $p = 0.010$, $d = 1.02$). Conversely, the *period of monitoring* was not a significant fixed factor in the "no improvement" group according to one-way ANOVA analysis ($F(2,29) = 2.96$, $p > 0.05$, $f = 0.45$). In the class 4O, where the assumption of normality was violated, a significant difference between the first and the last period was obtained according to MWU test ($U = 6$, $p = 0.004$, d[12] $= 1.78$) in the improvement group. Conversely, no significant differences were found in the "no improvement" group. In the class 2M, the period of monitoring is not a significant effect on average background noise levels of phase 2 according to one-way ANOVA analysis, as well as in the class 2N according to KW test.

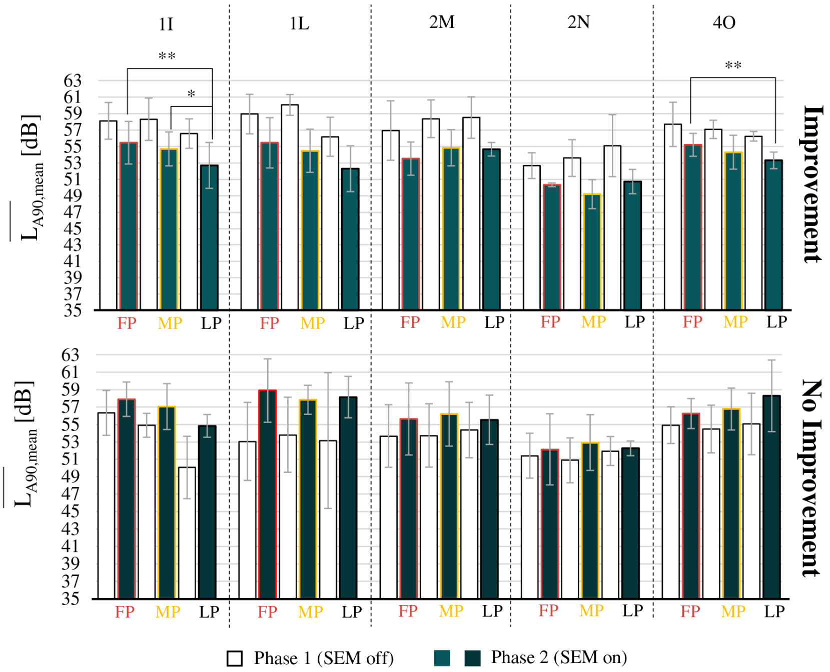

Figure 36. The average $L_{A90,mean}$ values of phase 1 and phase 2 over first (FP), middle (MP) and last (LP) period of P2, by considering the "improvement" and "no improvement" group. The bars of standard deviations are indicated. The $L_{A90,mean}$ values related to P1 are also reported as a reference. The significant differences between periods: * $p < 0.05$ and ** $p < 0.01$.

The main results are summarised as follows:

- the percentages of improvements were mainly concentrated in the first period of phase 2 in the second monitoring campaign, while they were split in the three periods of P2 in the third monitoring campaign.
- A decreasing trend in averaged $L_{A90,mean}$ values over the weeks of phase 2, in the presence of the lighting feedback, was found for the greater number of classes in the third monitoring campaign. The decrease was significant only in the class 1I and 4O in the "improvement" group.
- No significant differences were found in the "no improvement" group.

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[12] Estimates of effect sizes was manually determined through the Cohen's *d* equation based on the transformation from partial Eta-squared to *d* according to (Cohen, 2013)

These results seem to suggest that the motivational method led to a fulfilment over a long-term period in proactive behaviour of pupils in the third monitoring campaign, especially in two classes in the cases where the lighting feedback was effective. However, future works are needed to find the same significant trend for other classes and demonstrate the effective of the motivational method. Moreover, it is not possible to compare the two motivational approaches due to the small sample size of the second monitoring campaign.

3.1.5.5 Subjective assessments

This section is aimed at addressing these **research questions:** How do teachers assess the acoustic quality of classrooms? How do they perceive the presence of SEM device as an educational tool in classrooms also in relation to pupils' behaviour?

Subjective results are reported separately for each subject in order to evaluate whether the perceived acoustic conditions and the perception on SEM as an educational tool can be different in the same class, by considering also the explorative nature of this research. General considerations are also explained, independently of the teachers. Some questions are paired in order to highlight the relationship between the responses of related topics.

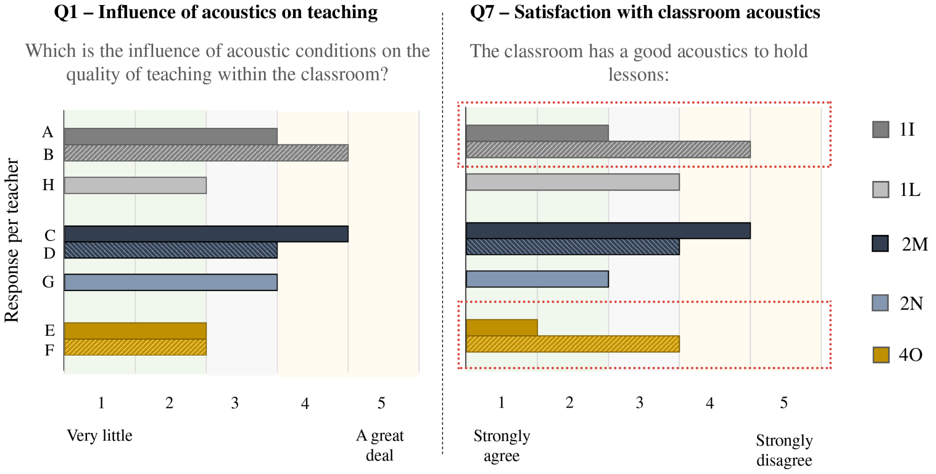


Figure 37. Section 2: teachers' responses related to influence of acoustics on teaching (Q1) and satisfaction with classroom acoustics (Q7). ID teacher is indicated with capital letter and the class is represented by the colour according to the legend. The dotted lines highlight the differences between teachers of the same class.

Figure 37 aims to evaluate the **influence of acoustics on teaching** (Q1) and the **satisfaction with classroom acoustics** (Q7), as well as the qualitative relationship between these two questions. The majority of the teachers does not perceive acoustics as an influential factor on the quality of teaching, as the average score is smaller than 3 out of 5. Good classroom acoustics is perceived from the majority of teachers. Only two teachers (B and C) declared that acoustics affects their teaching condition, and their level of satisfaction with classroom acoustics is low. In the classes 1I and 4O the teachers were differently satisfied with acoustic conditions, with opposite scores: from values 2 to 4 and from values 1 to 3 for the two classes, respectively. These results seem to suggest that the acoustic satisfaction is a strongly subjective factor.

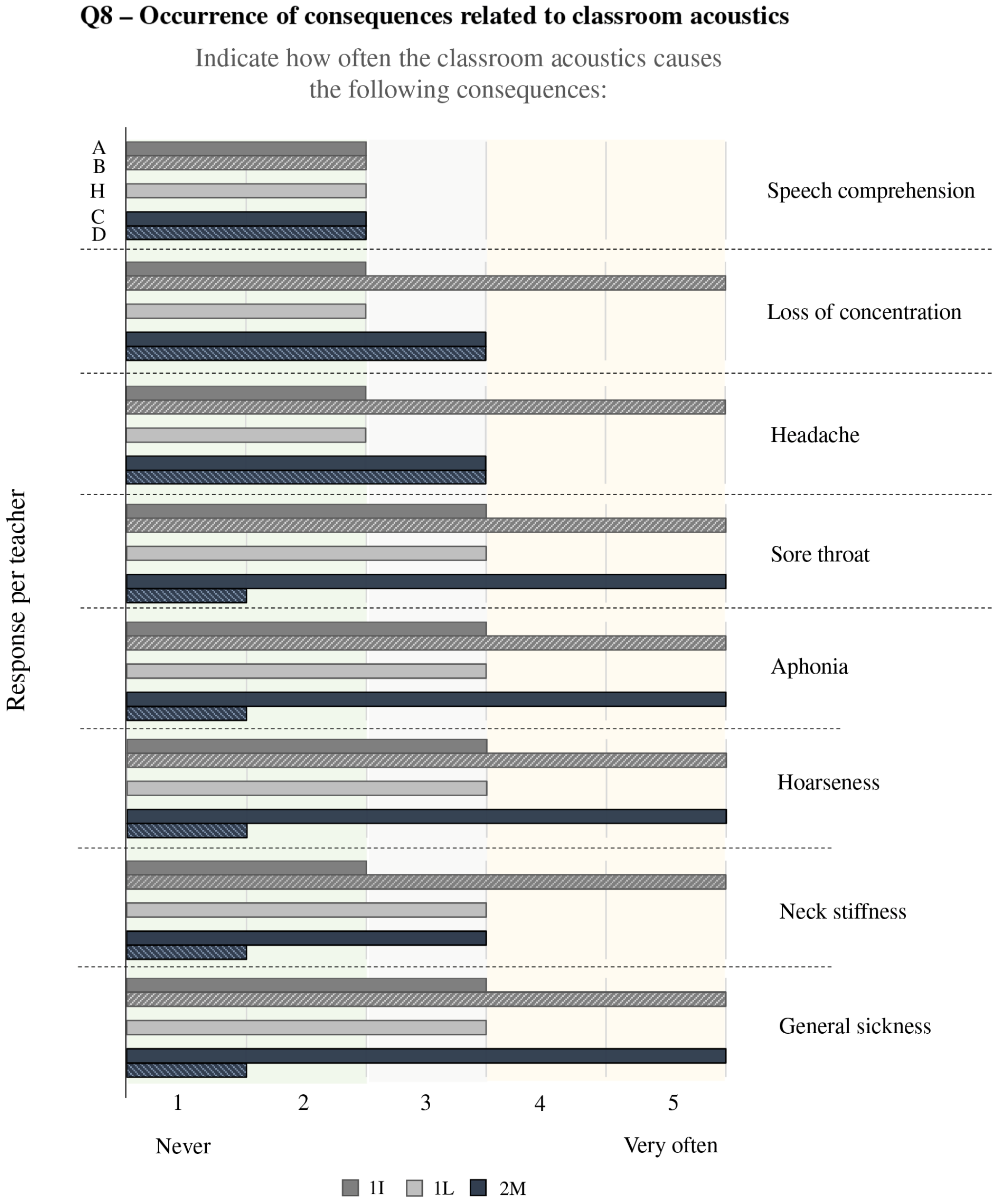
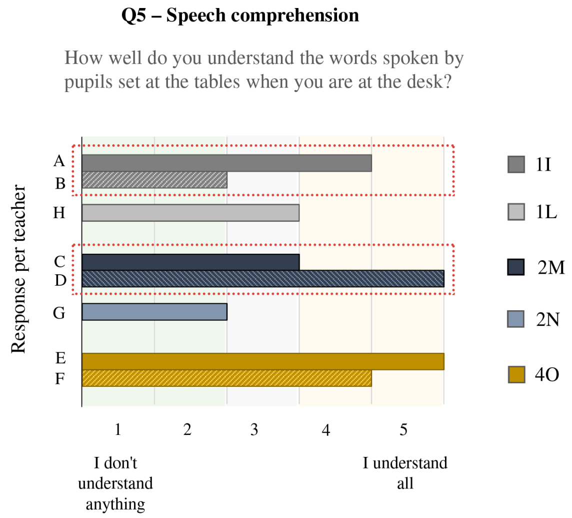


Figure 38. Section 2: teachers' responses related to occurrence of different consequences caused by poor classroom acoustics (Q8). ID teacher is indicated with capital letter and the class is represented by the colour according to the legend.

Figure 38 aims to investigate teachers' perception on the **occurrence of different consequences caused by poor classroom acoustics** (Q8). The responses of the teachers of the class 4O and 2M are not shown in the plot since they self-reported a score smaller or equal to 2 and, thus, classroom acoustics does not negatively affect their speech comprehension, vocal health and general well-being. This result is in line with the response of Q7 where teachers declared to be satisfied with classroom acoustics. In general, speech comprehension is not perceived as a consequence of poor acoustic design by all teachers; conversely, symptoms related to vocal apparatus, such as sore throat, aphonia and hoarseness, and general sickness, are considered the most important consequences related to poor acoustic condition, as the evaluation scores range between 3 and 5, except for one teacher (D). Negative consequences on vocal apparatus and general sickness are most frequently perceived by teachers B and C, who self-reported a low satisfaction with classroom acoustics (Q7 in Figure 37). Besides teacher B, the other subjects reported to be poorly affected by the acoustic condition, as the scores for loss of concentration, headache and neck stiffness are never greater than 3.

In accordance with the previous results on **speech comprehension**, Figure 39 shows that most of the teachers well comprehends the words of pupils when they are set at the tables. Two teachers (B and G) indicated poor speech comprehension, even if they reported a low frequency of occurrence of this consequence in relation to poor acoustic condition, as shown in Figure 38. A difference in perception of speech comprehension was found between the teachers of the classes 2M and 1I, with opposite scores from values 2 to 4.


Q5 – Speech comprehension

How well do you understand the words spoken by pupils set at the tables when you are at the desk?

Figure 39. Section 2: teachers' responses related to speech comprehension of pupils' words (Q5). ID teacher is indicated with capital letter and the class is represented by the colour according to the legend. The dotted lines highlight the differences between teachers of the same class.

Figure 40 shows that the majority of teachers perceived moderately high **background noise levels** (scores equal or greater than value 3) and increased **vocal effort** (scores equal or higher than 4), compared to the reference condition. A relationship between noise intensity and teachers' vocal effort was found for two teachers (B and F): they declared that noise levels were high in occupied classroom, as well as she tended to have a raised vocal effort during lessons. Thus, they needed to increase the voice level to cope with background noise. Conversely, teacher G perceived low noise intensity; as a consequence, also the vocal effort was not perceived to be high. This subjective result was qualitatively related to the objective one since the background noise levels were lower in the class 2N compared to the other classes (Figure 24).

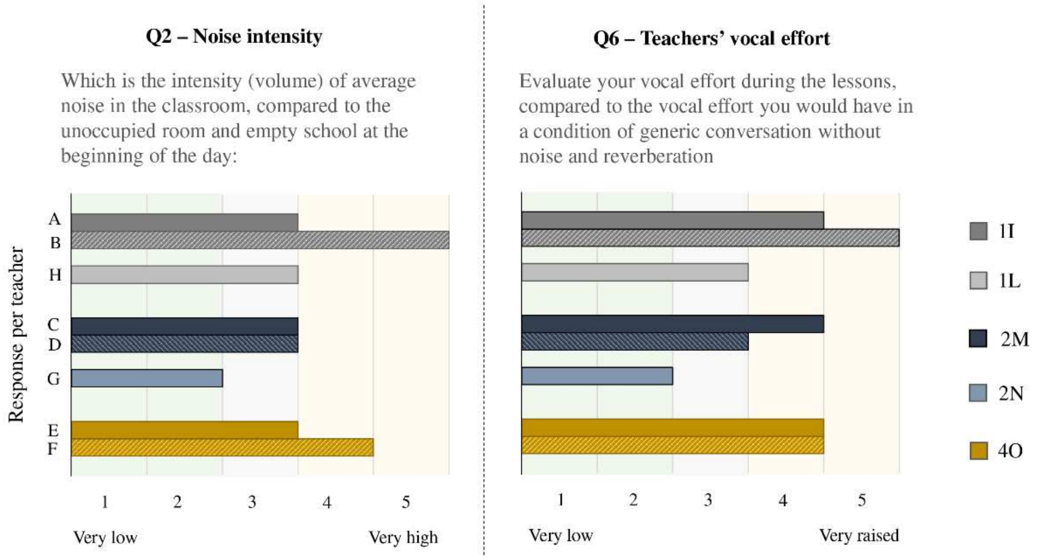


Figure 40. Section 2: teachers' responses related to noise intensity (Q2) and teachers' vocal effort (Q6). ID teacher is indicated with capital letter and the class is represented by the colour according to the legend.

Personal strategies generally used by teachers to reduce vocal effort and to improve intelligibility of the speech under noisy conditions have been reported in the open-ended question Q9. Such strategies include:

- remaining silent while looking pupils or raising the hand;
- changing the voice levels according to the situation;
- raising the hand and begin counting up to five;
- reducing voice volume;
- using gestures and glances;
- speaking slowly.

Concerning the question on **noise intensity, disturbance and frequency of occurrence for different sources**, the differences between these three aspects were equal or differed for one score, according to (Bottalico and Astolfi, 2012), where they were statistically correlated to each other. For this reason, results of perceived noise disturbance are only reported in Figure 41. Missing responses were found for teacher H.

External noise is not perceived as a main source of disturbance in all primary classrooms, as evaluation scores are never higher than 2. Indeed, the school building is set away from main roads and the classrooms either faced a road with low traffic or the internal courtyard, as mentioned in Section 3.1.1. In general, talking and moving generated by pupils inside the classrooms are perceived as the highest source of disturbance by teachers, with score above value 3. Teacher G declared that students talking and moving are not an annoying noise source in the class 2N (score of value 2). The disturbance caused by noise generated in the adjacent classrooms and in the corridor is only perceived by teacher A (score of value 4); probably, she uses to leave to door open more frequently than the other teachers. Some differences among the teachers of the same class have been found on the perception of noise disturbance, in particular in the class 2M in relation to student moving, and in the class 1I for student taking and moving in the corridor.

Q3 – Noise disturbance from different sources

Indicate the noise intensity, the degree of disturbance and occurrence frequency of the following noise sources in the classroom, compared to the unoccupied room and empty school at the beginning of the day:

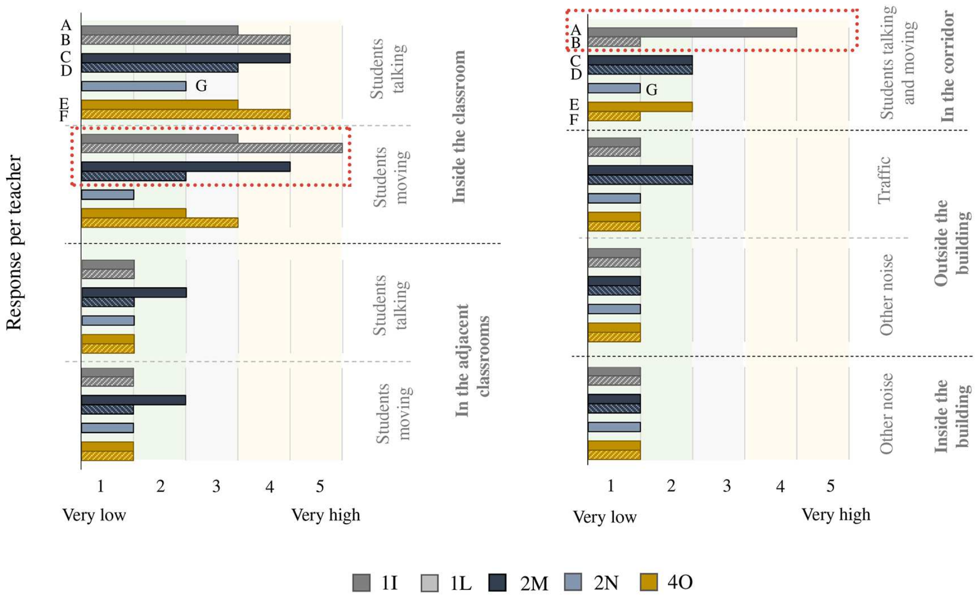


Figure 41. Section 2: teachers' responses related to disturbance generated by different noise sources (Q3). ID teacher is indicated with capital letter and the class is represented by the colour according to the legend. The dotted lines highlight the differences between teachers of the same class.

The results related to the perception on **reverberation of the sounds and voices** (Q4) is not reported since the responses were mostly in the middle option for all teachers, except for two of them that perceived sound and voice as dry.

Subjective assessments related to the **third section** of the questionnaire that aimed at better understanding **the use of SEM device** are explained hereafter.

Figure 42 shows the teachers' perception related to **pupils' behavioural change**: teachers of the classes 1I and 2N perceive a good level of attention of pupils towards the change of the SEM lighting feedback during traditional lessons, as the evaluation scores are greater or equal than 4. Conversely, one teacher of the class 4O declared that pupils did not pay attention to the variation of the lighting feedback (score of value 2). Teachers of classes 1L and 2M perceived a fair attention in pupils towards SEM device (score of value 3).

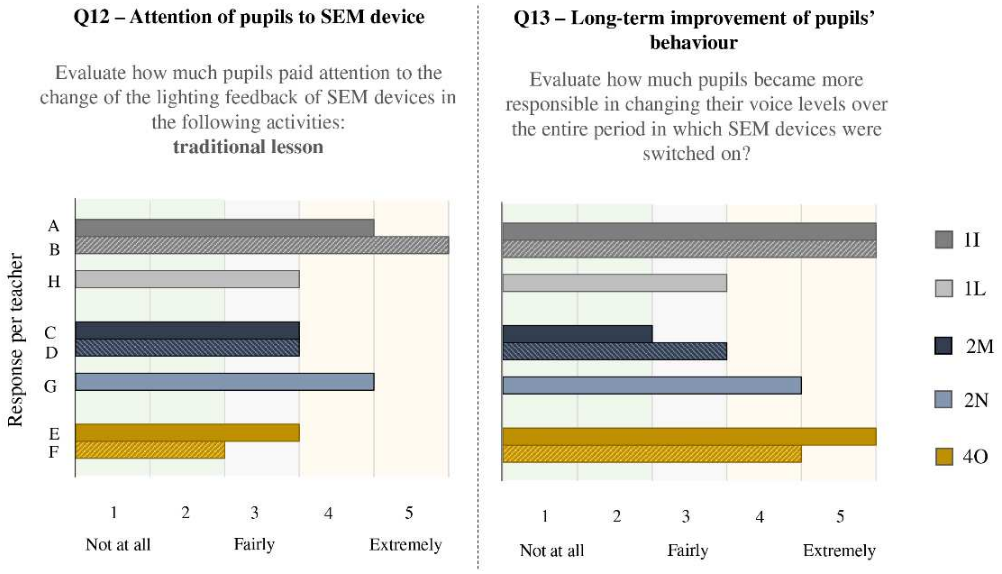


Figure 42. Section 3: Teachers' responses related to attention of pupils to SEM device (Q12) and long-term improvement of pupils' behaviour (Q13). ID teacher is indicated with capital letter and the class is represented by the colour according to the legend.

These results suggest a qualitative correlation between subjective assessments and objective results. Indeed, high percentage of improvements have been obtained in the classes 1I and 2N, respectively equal to 64% and 56% (Table 17), as well as high decrease of average background noise levels, equal to 3.4 dB(A) and 3.6 dB(A) (Table 18); conversely, opposite results have been found in the class 4O, where the improvement rate is equal to 41% (Table 17) and the decrease of average $L_{A90,mean}$ is equal to 2.9 dB(A) (Table 18).

Figure 42 also shows that most of the teachers perceived that pupils became more responsible in changing the voice levels over the entire period in which SEM devices were switched on; only teacher C reported the score of value 2. It is possible to note that teachers of the class 4O perceived an improvement in pupils' proactive behaviour over a long-term, however the level of attention toward the lighting feedback was overall low. This result seems to suggest that pupils' attention increased over the monitoring, probably because of the motivational method since a decreasing trend in averaged background noise levels found over the first, second and third periods of phase 2. Similarly, in the class 1I the increase of pupils' responsibility perceived by teachers is confirmed by the objective results on the effect of motivational method (Figure 36 in Section 3.1.5.4).

The **motivational method** based on the communication of the results by researcher was perceived as an effective way for motivating pupils over a long-term period (Q14). In particular, teachers self-reported that this method helps pupils to improve their behaviour over the monitoring encouraging to do well.

Figure 43 shows that **teachers of the classes 1I, 1L and 2N declared to be satisfied with SEM device for the reduction of noise levels** generated by pupils during traditional lesson: scores equal or greater than 4 have been recorded (Q10).

Conversely, lower satisfaction was perceived by teachers of the class 4O and 2M (score of value 2 and 3). Probably, the low level of pupils' attention in the class 4O was generated by the poor visibility related to the classroom layout, according to teachers' opinions. Despite the little positive effect of SEM device on pupils' proactive behaviour, the **teachers of the class 4O were still interested in SEM deployment in classrooms**, with score of value above 4 (Q15). Only one teacher of the class 2M declared a low interest for the lighting feedback (score of value 2), compared to other teachers that were fairly or very interesting in the use of SEM device.

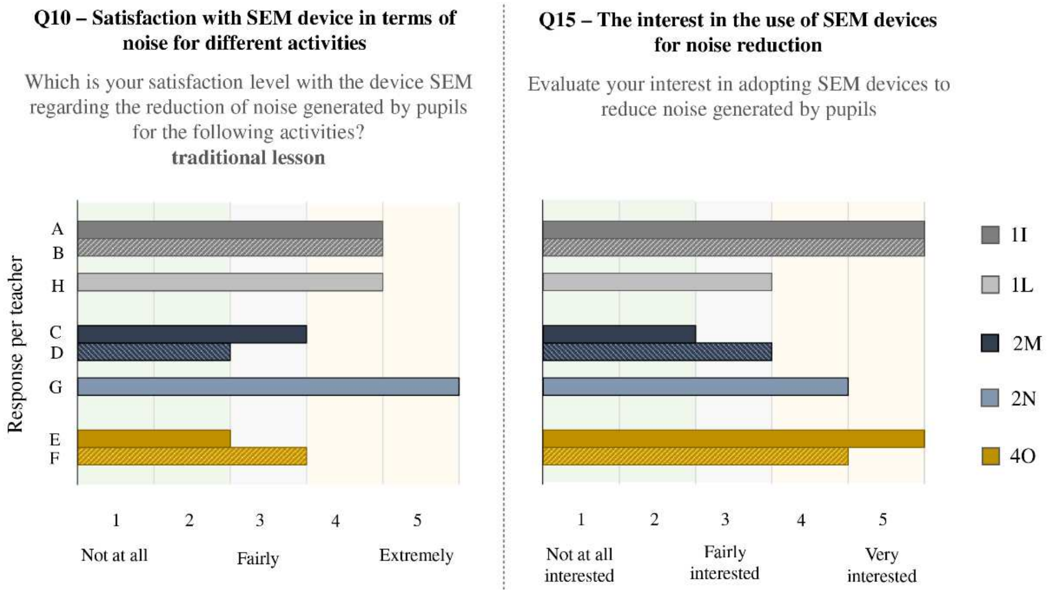


Figure 43. Section 3: teachers' responses related to satisfaction with SEM device in terms of noise reduction (Q10) and their interest in the use of SEM device (Q15). ID teacher is indicated with capital letter and the class is represented by the colour according to the legend.

Teachers self-reported in Q11 that the **vocal effort** decreased when the lighting feedback was switched on. However, only few of them motivated their answer by stating that this reduction was a consequence of the proactive pupils' behaviour related to the presence of the lighting feedback. It is interesting to report the general opinion (Q16) of the teacher B of the class 1I: "*The lighting feedback is a friendly tool that motivates self-adjustment in pupils' promoting an improvement in their behaviour. The communication of results over the monitoring encourages them to do better.*"

The main results are summarised as follows:

- the majority of teachers perceived good classroom acoustics.
- Differences in perception of acoustic condition, comprehension of pupils' speech and frequency of noise disturbance sources were found among teachers of the same class.
- Symptoms related to vocal apparatus (i.e. sore throat, aphonia and hoarseness, and general sickness) were considered the most important consequences related

to poor acoustic condition, especially by two teachers who were low satisfied with classroom acoustics.

- The background noise levels perceived by teachers was mainly generated by talking and moving of pupils inside the classrooms.
- Most teachers perceived good or fairly good level of attention of pupils towards the SEM lighting feedback during traditional lessons.
- Teachers of three classes were satisfied with SEM device in terms of noise reduction generated by more aware pupils' behaviour, while a lower satisfaction with SEM device was perceived by teachers of the class 4O and 2M.
- One teacher declared a low interest for the lighting feedback, compared to all the other teachers that were fairly or very interesting in SEM deployment in classrooms.
- A qualitative relationship between objective measurements and subjective ones was found in terms of attention of pupils to SEM device and measurements of background noise levels.

These explorative results are reported to document the study, to better understand some objective results and to highlight differences between teachers and classes in the assessments of classroom acoustics and the use of SEM device as an educational tool. However, the aforementioned results cannot be generalized, thus they will be not further discussed in the subsequent section.

3.1.5.6 Discussion

Background noise levels and acoustic characteristics of classrooms are key factors in the learning and teaching processes. Physical interventions, such as enhancing sound absorption treatments and sound insulation, or reducing distance between student and teachers, are typically used to improve learning environment. In addition, a focus on occupant behaviour is emerging in literature to reduce background noise levels and improve acoustic comfort. Moreover, in a context where open-plan classroom is an ongoing trend, the necessity to promote' engagement of teachers and pupils and their awareness in terms of noise production could become an important research theme. However, the tendency to enclose active engagement of teachers and pupils in projects of acoustic improvements is still on a small scale, thus the present work can be considered an exploratory research, which sets the base for future work.

Thirteen classes of a primary school in Turin (Italy), for a total of 290 pupils and 25 teachers, were involved over 3 school years in a long-term monitoring campaign. During each school year, the monitoring campaign was split into two phases, respectively characterized by the absence or the presence of SEM lighting feedback. Questionnaires were administrated to the teachers at the end of the third monitoring campaign with the aim to investigate the perceived acoustic quality of classrooms, as well as the qualitative relationship between the objective data and the subjective assessments in terms of usefulness of SEM devices on pupils' behavioural change.

Independently from the two phases, the average background noise levels during traditional lessons ranged from 48.0 dB(A) to 51.9 dB(A), 52.2 dB(A) to 56.5 dB(A) and 52.3 dB(A) to 57.3 dB(A) in the first, second and third school year respectively. In the first monitoring, background noise levels measured in traditional lessons were similar to the findings of (Bottalico and Astolfi, 2012), that are 50 dB(A) to 53 dB(A). Conversely, the average background noise levels found in the second and third scholastic year were closer to the highest average background noise levels of 56 dB(A) found in (Puglisi et al., 2017), in which the noise levels were related to the entire lesson. Indeed, the researchers asked to teachers to behave as they usually did during the teaching hours. One consideration can be raised by the latter result: lessons were characterized by random noise levels typical of primary school caused by pupils' behaviour. Indeed, they tend to interact with teachers and each other, move around the room or move chairs and objects, also in traditional lessons contrary to its definition: students seat at their desks and listen to the teacher who is speaking at her/his desk or close to the blackboard. The lower variability in background noise values between the classes were found in the third monitoring campaign compared to other ones.

Overall, the range of average L_{A90} found in the present study correspond to the average values found by (Shield and Dockrell, 2004) in traditional, individual and group work lessons, equal to 45.8 dB(A), 52.1 dB(A) and 58.6 dB(A). However, the typical situation of Italian primary classroom could be different from the English one, therefore detailed considerations are not reported on the comparison between their results with those of the present study.

Average statistically significant decreases of 1.6 dB(A) and 2.4 dB(A) were found when the lighting feedback was switched on in the first- and second-grade classes, respectively, during the third monitoring campaign. The fixed factors, such as *teacher*, *time-band*, *day of week* and *number of pupils,* were not controlled in this analysis in order to compare the results with previous study by Van Tonder et al. (2016). This latter demonstrated that the use of the lighting feedback (SoundEar II) led to a significant decrease of average noise levels by 1.4 dB(A) within three first- to third-grade classes. Although these results are in line with the results of the present dissertation, the values were not reported separately for each class and, however, the result refers to a short period of classroom activities (36 hours).

The factorial analysis of variance highlighted that the effects of fixed factors, such as *teacher*, *time-band*, *day of week* and *class*, were significant on background noise levels, independently of the presence of the lighting feedback. Some degree of interactions emerged between the effect of the fixed factors and the effect of the lighting feedback on dependent variable ($L_{A90,mean}$), even if only one interaction between *day of week* and lighting feedback was statistically significant. The effect of lighting feedback was not significant on background noise levels, except in the class 1I in one statistical model. Overall, the estimation of the effects of the fixed factors and their interaction with SEM device on background noise levels should be carried out to have a deeper evaluation of the effect of the lighting feedback on background noise levels in classrooms.

With respect to the analysis where all fixed factors were controlled, the following considerations can be done. A significant decrease of background noise levels was obtained when the lighting feedback was switched on for a total of 51% pairs of independent lessons. These decreases emerged when the starting noise conditions were worse, i.e. the background noise levels were highest in the absence of the lighting feedback. In the remaining cases (49%), background noise levels increased, or the decrease did not reach a statistically significant level. Several reasons may be hypothesised for this result: for example pupils paid smaller attention towards the lighting feedback because the activities required more interaction between them and teachers. The background noise levels were not extremely annoying to require a behavioural change. Moreover, the engagement of teachers aimed at motivating pupils to follow the lighting feedback was lower. However, the increases of background noise levels were lower compared to the decreases of background noise levels when the lighting feedback was switched on, excepted in two classes in the second and third monitoring campaigns.

The effect of SEM devices in terms of background noise levels reduction was higher in the first monitoring campaign, follow by the third monitoring ones. In particular, the activation of the lighting feedback led to an average decrease of 3.2 dB(A) and 3.3 dB(A) versus an increase of $L_{A90,mean}$ values of 1.6 dB and 2.5 dB, respectively, in the first and third monitoring campaigns. Conversely, a lower improvement in terms of noise reduction was generally obtained in the second monitoring campaign: an average decrease of 2.2 dB(A) was found versus an increase of $L_{A90,mean}$ values of 1.9 dB.

In the third school year, the percentages of “improvements” in terms of noise levels were split over the period when the lighting feedback was switched on in the majority of classes. A significant decrease of background noise levels was only found in one first- and fourth-grade classes when the lighting feedback was found effective. This positive result may in part be caused by the introduction of the motivational method based on the constant feedback provided by the researcher to pupils on results achieved in the previous week. However, future works are needed to verify the presence of the same trend in other classes and to improve the reliability of the results.

The noise reduction generated by more aware behaviour of pupils based on the presence of SEM devices was perceived by the largest number of teachers, indeed they overall declared to be interested to use it as an educational tool. However, these results cannot be generalized due to the small sample size, and it is not possible to compare them with previous study (Prakash et al., 2011). In this latter, teachers perceived a reduction of noise levels after the installation of the lighting feedback, as well as an improvement on the learning environment. A large sample of teachers form different schools, equal to 100, were involved in (Prakash et al., 2011).

Overall, some qualitative considerations arose by the subjective assessments and the discussion between researcher and teachers developed during the focus groups and the visit of the researcher weekly in third monitoring campaign. In the class 1I, where teachers were strongly committed in deploying SEM device as educational tool, a high decrease ($\Delta L_{A90,mean}$ = 3.4 dB) and a low increase ($\Delta L_{A90,mean}$ = 1.8 dB) of background noise level was found in the presence of the lighting feedback. Thus, the positive effect of the lighting feedback on pupils' behavioural change could be motivated by the great interest of the teacher in SEM device. Moreover, the poor visibility caused by table layout in small groups used in the fourth-grade class seems to be the crucial factor in the lower level of pupils' attention towards the lighting feedback of SEM device and, consequently, in the noise reduction ($\Delta L_{A90,mean}$ = 2.9 dB).

3.1.5.7 Limitations and proposals for future investigations

Some limitations related to the data sample and methodology have been found in the three monitoring campaigns. The main limitations and proposal for improvement may be summarized as follows:

- The duration of 6 weeks of the first and second monitoring campaigns led to have small sample sizes. This limitation led to a smaller reliability of results of each analysis, compared to the outcome of the third monitoring campaign.
- The information related to the lesson starting and ending points and the outside noise only relies on the timesheet filled in by teachers. Therefore, possible external noise events may not have been excluded completely by the analysis, as well as undefined and uncontrolled variables. Moreover, it is possible that periods in which students interact with teachers and each other, move around the room or move chairs and objects were included in the analysis, even if only traditional lessons were analysed. Indeed, the variability of the background noise levels during traditional lessons is strongly affected by pupils' behaviour, this means that the typical condition of traditional lesson, in which only one person is speaking, may not be in each lesson used in the analysis. However, this means that the results of present study represent the real situation of Italian school classrooms in terms of background noise levels.
- The absence of a multidisciplinary approach able to include expertise on acoustic environmental quality, anthropology, pedagogy and educational subject is considered a limitation for several reasons. For example, a multidisciplinary approach can be useful in the definition of motivational methods and in the subjective evaluation of pupils' behavioural change.
- The absence of the questionnaire addressed to teachers in the first and second monitoring campaign led to a small sample size in the subjective investigation, and consequently, the generalised conclusions cannot be drawn.
- The absence of the questionnaire addressed to pupils in order to evaluate their interest in the lighting feedback system and their noise awareness was also identified as a limitation.

- The possible reasons on the ineffective of the lighting feedback system could be deeply investigated in the future works improving the questionnaire.
- The investigation involved the classrooms of the same schools in which the cultural context could be similar, therefore the need to involve different schools raised from this PhD research.

3.1.6 Results and discussion: pilot study on long-term monitoring of teachers' vocal behaviour

3.1.6.1 Effect of SEM device on voice and noise

Lombard effect

This section is aimed at addressing this **research question:** Do the teachers' voice levels decrease when the lighting feedback of SEM devices is switched on in classrooms?

Figure 44 shows the minimum, mean and maximum values of sound pressure level at 1 m form the teacher's mouth against the background noise levels for both phases 1 and 2. As shown in Figure 21 in Section 3.1.4, background noise levels are discretized in 3 dB intervals.

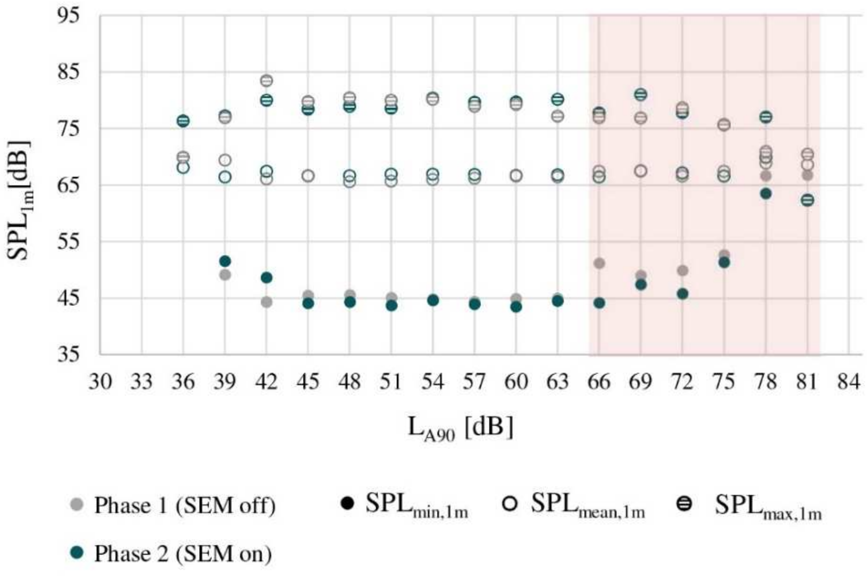


Figure 44. Minimum, mean and maximum values of sound pressure level at 1 m from the teacher's mouth ($SPL_{min,1m}$, $SPL_{mean,1m}$, $SPL_{max,1m}$) for phases 1 and 2 *vs* background noise levels (L_{A90}) grouped in 3 dB range.

The results show that teachers tend to use the voice within the overall range of vocal effort that ISO 9921 defines in the range between "relaxed" (54 dB(A)) and "very loud" (78 dB(A)) with background noise levels between 45 dB(A) and 63 dB(A). In this range of L_{A90} levels, minimum, maximum and mean SPL values are almost constant. Conversely, for higher values of background noise (values up to 81 dB(A) have been recorded), a different teachers' vocal behaviour is found. Indeed, a trend toward raised vocal effort, with an increased average value – close to 68.5 dB according to ANSI (ASA, 2012) – and a smaller variability – i.e. a smaller difference between $SPL_{max,1m}$ and $SPL_{min,1m}$ – have been found. This means that teachers do not rise the voice levels above 80 dB even in case of extremely high noise levels. On the other hand, they tend to increase the voice levels above the relaxed vocal effort, that is 56.5 dB considering an increase by 2.5 dB for conversion to Z-weighted levels according to (Carullo et al., 2014).

According to these results, a relation between an increase in the speech level with background noise level is found only in $SPL_{min,1m}$ (Figure 45) based on linear regression analysis (A6).

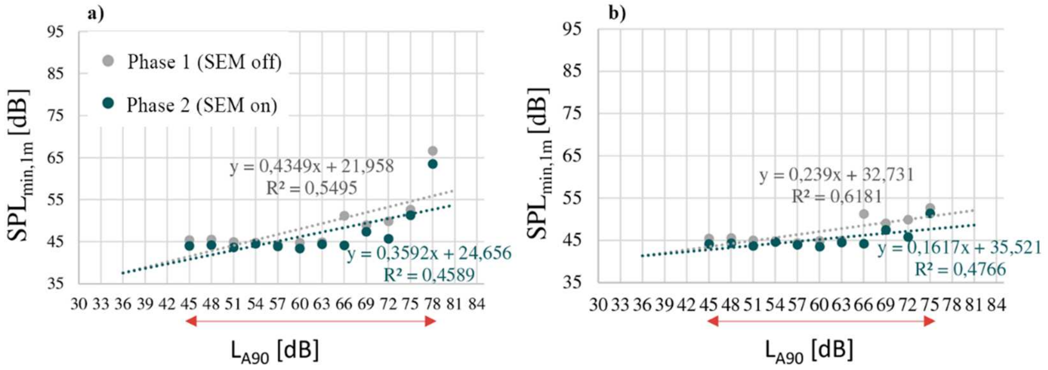


Figure 45. Linear regressions between minimum values of sound pressure level at 1 m from the teacher's mouth ($SPL_{min,1m}$) and background noise level (L_{A90}) for phase 1 and 2. L_{A90} values range differently in figure a) and b).

Previous studies on the Lombard effect obtained that the noise level has minimal effect on the speech level for noise levels up to 30-50 dB(A) (Gardner, 1966; Korn, 1954; Lazarus, 1990) and saturation in the voice level appears, due to physiological limitations in very high noise levels (Bottalico et al., 2017). According to the latter results, a saturation seems to be from 78 dB (A) to 81 dB (A) where the $SPL_{min,1m}$ are distributed on a horizontal line. The regression lines on the data samples were first evaluated in a range of background noise between 45 dB(A) to 78 dB(A), where an increase in the speech level of 0.43 dB ($R^2 = 0.54$) and of 0.35 dB ($R^2 = 0.45$) per 1 dB (A) increase was found in phase 1 and phase 2, respectively. In line with the slope range indicated by Lazarus (1990), that is 0.3-0.6 dB increase in speech level per noise level rise of 1dB, a tendency towards Lombard effect seems to exist in both the two phases. This tendency decreases below the typical slope of the Lombard effect when the range of background noise was from 45 dB(A) to 75 dB(A), excluding all values of the horizontal line. Thus, an increase in the speech level of 0.23 dB ($R^2 = 0.61$) and of 0.16 dB ($R^2 = 0.48$) per 1 dB (A) increase was obtained in phase 1 and phase 2, respectively.

Overall, a lower tendency to raise voice levels exists when the lighting feedback of SEM was switched on, according to both the two linear regression analysis.

Vocal effort and background noise level on overall data sample

This section is aimed at addressing this **research question:** Is there a significant difference in terms of voice levels and background noise levels when SEM devices are switched on, independently from the subjects?

Table 22 shows that the mean sound pressure level at 1 m from the teacher's mouth were on average 66.5 (s.d. = 6.0) and 66.8 dB (s.d. = 6.1) over the long-monitoring for phases 1 and 2, respectively. These values are in the range between the "normal" and "raised" vocal effort according to ANSI S3.5-1997 (ASA, 2012). Further, mean L_{A90} values were on average 53.3 dB(A) and 53.8 dB(A) for phases 1 and 2, respectively.

Therefore, contrary to the hypothesis of the present study, the average values of the voice and noise parameters were slightly higher in phase 2 compared to phase 1 when the overall sample was considered in the analysis.

Table 22. Mean and standard deviation (s.d.) values of SPL_{1m} and L_{A90} occurrences distributions for phase 1 and phase 2, and the right-tailed *p*-values of significance of the differences between both phases, according to the MWU test. Results are reported separately for each teacher (T) and pair of the long-term monitorings (M). Any statistically significant differences are reported in bold.

Class	**T**	**M**	**Parameter /dB**	**SEM off Phase 1**		**SEM on Phase 2**		**Δ_{P2-P1}/dB**	**MWU test right-tailed *p*-value**
				Mean	**s.d.**	**Mean**	**s.d.**		
2M	C	1	SPL_{1m}	67.6	3.9	67.1	4.8	-0.5	0.09
			L_{A90}	56.7	7.6	58.1	5.7	1.4	1.00
2M	D	1	SPL_{1m}	63.7	6.0	68.5	6.3	4.8	1.00
			L_{A90}	52.9	5.3	54.1	6.4	1.2	1.00
2M	D	2	SPL_{1m}	64.8	7.3	65.7	6.7	0.9	1.00
			L_{A90}	51.4	6.2	55.0	6.2	3.6	1.00
2N	G	1	SPL_{1m}	**70.2**	**6.9**	**67.9**	**5.6**	**-2.3**	**< 0.001**
			L_{A90}	**50.5**	**5.6**	**47.5**	**5.9**	**-3.0**	**< 0.001**
4O	E	1	SPL_{1m}	**66.1**	**5.9**	**64.9**	**7.2**	**-1.2**	**< 0.001**
			L_{A90}	**55.0**	**7.6**	**54.4**	**7.4**	**-0.6**	**0.036**
			Average SPL_{1m}	66.5	6.0	66.8	6.1	0.3	
			Average L_{A90}	53.3	6.5	53.8	6.3	0.5	

Vocal effort and background noise level for each long-term monitoring

This section is aimed at addressing this **research question:** How does SEM device affect the vocal effort of each teacher and the background noise levels, class-by-class?

Table 22 also shows the mean values of SPL_{1m} and L_{A90} related to each long-term monitoring in order to take into account the inter-speaker variability (Castellana et al., 2017). The *p*-values of the right-tailed MWU test indicate the acceptance of the alternative hypothesis based on the assumption that the sound pressure levels and the background noise levels were higher in phase 1 compared to phase 2, assuming the positive effect of the lighting feedback of SEM device on occupant behaviour. Looking at the values of each long-term monitoring, a significant decrease of SPL_{1m} of 2.3 dB and 1.2 dB was found during the pair of the long-term monitorings according to MWU test for teachers G ($U = 360397$, $p < 0.001$, $d^{13} = 0.52$) and E ($U = 1005576$, $p < 0.001$, $d^{15} = 0.18$) in the classes 2N and 4O, respectively, where a significant decrease of L_{A90} by 3.0 dB(A) and by 0.6 dB(A) were obtained in phase 2, respectively, according to MWU test (2N: $U = 618622$, $p < 0.001$, $d^{15} = 0.53$; 4O: $U = 1588619$, $p < 0.05$, $d^{15} = 0.06$). However, the moderate effect sizes were found only for teacher G in the class 2N. Conversely, the background noise levels did not decease significantly for all pair of the long-term monitorings related to class 2M, where different vocal behaviours were found for the two teachers. Indeed, the average significant increase of SPL_{1m} by 2.9 dB was measured for teacher D in phase 2, consistently with the increase in background noise levels of 2.4 dB(A), while no significant decrease of SPL_{1m} by 0.5 dB was found for the teacher C with an increase of 1.4 dB(A) in L_{A90}.

The high values of the standard deviations of individual averaged SPL_{1m} reveal the high intra-speaker variability in terms of vocal effort used by teachers during traditional lessons. In accordance with voice parameters, high variation of averaged background noise levels was found for each class, confirming that the extended range of background noise levels is typical in primary school activities (Bottalico and Astolfi, 2012; Sato and Bradley, 2008).

The vocal behaviour and background noise levels detected during the phase 1 and phase 2 are also represented in Figure 46 where histograms of the SPL_{1m} and L_{A90} occurrences related to each pair of the long-term monitoring are shown for each teacher. In accordance with the hypothesis of the present study, the histograms

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[13] Estimates of effect sizes was manually determined through the Cohen's *d* equation based on the transformation from partial Eta-squared to *d* according to (Cohen, 2013)

effectively show that some teachers and classes were positively affected by the presence of the lighting feedback of SEM devices and others were not.

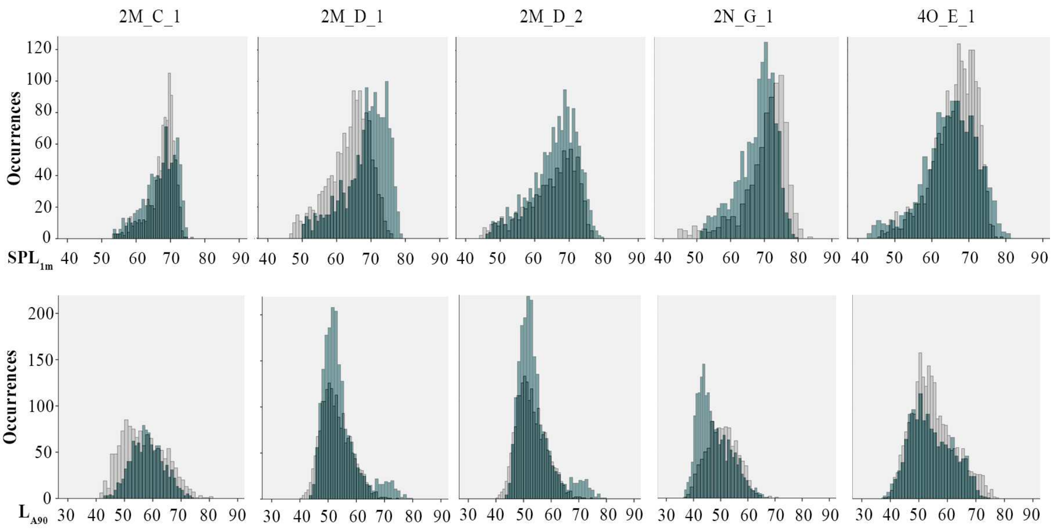

Figure 46. Histograms of SPL_{1m} and L_{A90} occurrences related to the pair of the long-term monitoring according to phase 1 and phase 2. The ID code of each monitoring was reported on each histogram.

3.1.6.2 Effect of SEM device on subjective assessments

This section is aimed at addressing this **research question:** How do teachers perceive their vocal status, noise condition and voice intensity with and without SEM devices?

Figure 47 shows that teachers perceived no or mild voice problems during the long-monitorings of both phases, except teacher C, who perceived moderate voice problem during a working day of phase 1, thus when the lighting feedback of SEM devices was switched off.

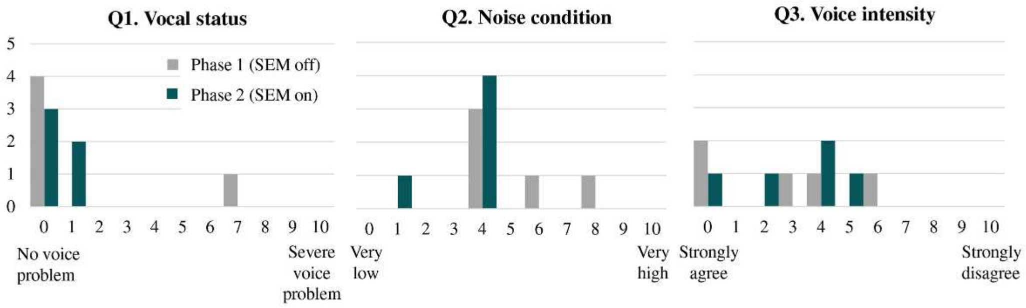

Figure 47. Subjective evaluation on vocal status, noise condition and voice intensity perceived by teachers at the end of each long-term monitoring divided into phase 1 and phase 2.

The intensity of noise compared to the situation of unoccupied classroom and empty school at the beginning of the day was perceived higher during the long-term monitoring when the lighting feedback of SEM devices was switched off. Teachers had to use higher voice levels compared to the ideal condition without background noise and reverberation during the greater number of long-term monitoring, independently of the lighting feedback of SEM devices. Some teachers answered this question with a neutral response.

3.1.6.3 Discussion

Classroom is an environment shared between pupils and teachers where high background noise levels mainly generated by pupils themselves tend to negatively affect learning and teaching process. From the teachers' side, the presence of the lighting feedback of SEM device could promote more aware vocal behaviour and help avoiding incorrect use of their voice.

In the present pilot study, four female teachers of three second-grade and fourth-grade classes performed long-term voice monitorings during 10 traditional lessons in phases 1 and 2, respectively, without and with the SEM lighting feedback.

The mean sound pressure levels of the speech at 1 m from the teacher's mouth were on average 66.5 (s.d. = 6.0) and 66.8 dB (s.d. = 6.1) in phases 1 and 2, respectively, ranging between the "normal" and "raised" vocal effort according to ANSI S3.5-1997 (ASA, 2012). Different vocal behaviours emerged between low/moderate and high background noise level, indeed teachers tend to alternate their voice levels in the above range of "relaxed" up to "very loud" of vocal effort when the background noise levels were low or moderate; conversely, they decrease voice levels from very loud to raised vocal effort under high noise levels due to physiological limitations (Bottalico et al., 2017). On the other hand, it seems that they used lower voice levels under relaxed vocal effort tending toward values of raised vocal effort.

In a long-term voice monitoring study in primary schools, Bottalico and Astolfi (2012) observed a 0.72 dB increase in mean sound pressure level at 1 m from the teacher's mouth per 1 dB increase in noise level values during traditional lesson. Therefore, a higher increase in the speech levels was found in relation with lower background noise levels (L_{A90}) from 40 dB(A) to 65 dB(A), compared to the present pilot study where only a trend toward Lombard effect was obtained in a range of background noise levels between 45 dB(A) to 78 dB(A). This could be related to the difference between the two studies in terms of definition of traditional lessons period, as further explained in Section 3.1.5.2.3. It is important to note that in a recent study, Puglisi et al. (2017) found a 0.53 dB increase in speech level per 1 dB increase in noise level (L_{A90}) considering the entire working day (4 hour) of primary school teachers, where the background noise levels ranged between 50 dB(A) to 70 dB(A). This range is similar to the results found in the present study showing that voice signals analysed include the typical vocal behaviour used by teachers during the teaching hours, and not only during the traditional lesson, differently by the aim of this pilot study. Further investigations are needed in order to better understand how teachers rise their voice level during the entire working day including time-slots of activities other than traditional lessons.

Based on the main goal of this pilot study, it is important to note that on overall data sample a lower tendency to raise voice levels exists when the lighting feedback is switched on. In particular, two teachers of second and fourth grade classes significantly decrease their vocal effort in relation with the significant reduction of background noise levels. However, the effect sizes demonstrate that one on them was positively and moderately affected by the presence of the lighting feedback of SEM devices. Conversely, the background noise levels did not decrease when the lighting feedback was switched on in one second-grade class; consequently, the vocal effort of the two teachers did not significantly decrease. Overall, all teachers perceived a reduction in noise intensity compared to the reference condition at the beginning of the day, while the perceived voice intensity was remained the same during the long-term monitorings with the lighting feedback of SEM devices on. Thus, a correspondence between objective and subjective parameters was not found.

In accordance with Castellana et al. (2017), a high intra-speaker variability emerged for each teacher, as well as the high var iation of averaged background noise levels confirming that the extended range of background noise levels is typical in primary school activities (Bottalico and Astolfi, 2012; Sato and Bradley, 2008).

3.1.6.4 Limitations and proposals for future investigations

The present study is a starting point for future investigations, thus it is necessary to acknowledge some limitations related to the data sample and methodology. The main limitations and proposals for improvement may be summarized as follows:

- The small sample size and the little number of long-term monitorings for each teacher led to the low power of the conclusions. Since Bottalico and Astolfi (2012) found that the variation in the vocal effort of teachers can be significantly different in the morning, compared to the afternoon periods, a greater number of paired long-term monitoring should be performed for each teacher taking into account the day of week and the period of the working day.
- The detection of traditional lessons using the timesheet filled in by teachers may be subject to uncertainty. Looking the time history of the signal, the time slots of traditional lessons, where the difference between sound pressure levels and background noise is high because teacher is speaking and pupils are listening, are limited compared to the entire voice signal. In other words, this means that the entire voice signal analysed included the randomness typical of the noise of children in primary school caused by different type of activities (Bottalico and Astolfi, 2012; Shield and Dockrell, 2004). This limitation could explain the tendency to raise voice levels in the minimum values that indicated the comfort voice emission. According to previous study (Calosso et al., 2017), the detection

of the traditional lessons was carried out by the researcher present in classrooms during the lessons. As mentioned above, the presence of the research in classrooms should be avoided since an external operator may disturb occupants or cause the Hawthorne effect (Wagner and Brien, 2018; Adair 2000; Seligman et al., 1978), thus a methodology based on the detection of the starting and ending point of traditional lessons in post processing should be studied. For example, the typical noise levels of different type of activity indicated in (Shield and Dockrell, 2004) could be used for detection of traditional lessons.

- Considering the inter-subject differences, the R-squared values of the regression lines were not particularly high, this means that all the obtained relationships can be considered as tendencies only.

3.1.7 Guidelines for future application of the lighting feedback system in classrooms

The adoption of lighting feedback systems to encourage and assess behavioural change of pupils and teachers is still limited, in particular over long-term periods, as mentioned in Chapter 1. Therefore, the present PhD project aims to extend the state of the art in this field and the long-term monitoring campaigns tend to explore novel methodologies and to find novel results.

This section aims to draw guidelines for future researches on the introduction of the lighting feedback system as an educational tool in classrooms according to the main findings of this dissertation. The key factors to control are listed in Figure 48 and described in detail below.

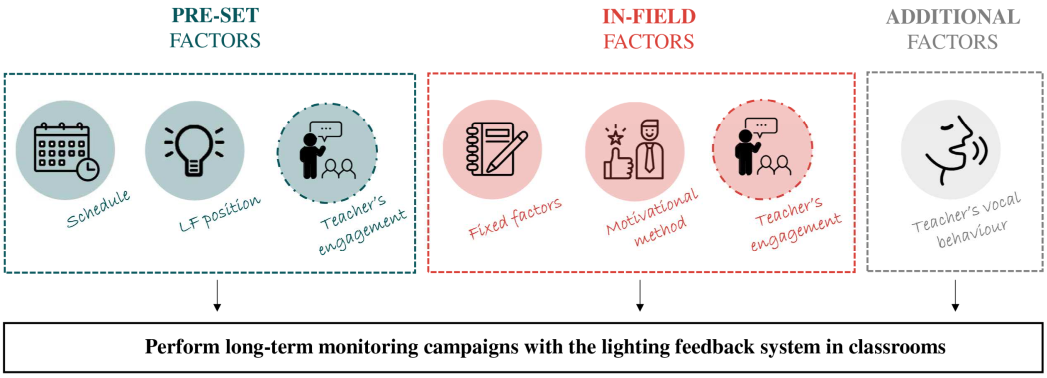

Figure 48. Overview of key factors to control for future application of the lighting feedback system in classrooms.

Schedule and duration of the monitoring campaign

The monitoring campaign must be split in two phases, respectively without and with the lighting feedback. An additional monitoring campaign without the lighting feedback can be planned after the second phase, in order to evaluate the level of noise awareness achieved by the students. The first phase should last at least 4 weeks, while the minimum duration recommended for the second phase is 8 weeks.

Additional weeks can be useful to address any unforeseen problems caused by external variables.

Position of the lighting feedback system

In case of traditional classroom layout, the lighting feedback system must be located on the frontal side of the classroom (i.e. close to the blackboard/whiteboard or teachers' desk); conversely, in case tables are clustered in small groups, several systems are needed, in order to ensure visibility. In the latter case, the small table devices are more suitable for adoption.

Indication and evaluation of fixed factors

A paper logbook or alternative methods (i.e. daily activities and time tracking tools) are needed to collect the fixed factors, such as *class*, *type of activity* and its *time-band, teacher, number of pupils* and *day of week*. Indeed, the estimation of the effects of the fixed factors and their interaction with SEM device on background noise levels should be carried out to have a deeper evaluation of the effect of the lighting feedback on background noise levels in classrooms.

Motivational method

A motivational method to promote the fulfilment of long-term behavioural changes may be needed in addition to the lighting feedback system. For example, the trend of green, yellow and red light colours can be plotted on the whiteboard or on a dedicated poster, as well as a report containing the overall results can be distributed in each involved class. The involvement of the researchers in these motivational activities could be an effective way to further encourage proactive behaviour of pupils on a long-term.

Engagement of teachers

Teachers' interest and engagement in the project since the early stage of the project is crucial. Therefore, a bottom-up approach is necessary to improve their attitude in adopting the lighting feedback as an educational tool. Moreover, a brainstorming process is needed to plan the effective motivational method and to classify the type of lessons that usually are performed in class in order to avoid issues of interpretation in the timesheet.

Monitoring teachers' vocal behaviour

Long-term voice monitoring sessions should be performed to investigate how the noise reduction led by the lighting feedback system can change the teachers' vocal activity. Indeed, this system could be used as a tool supporting teachers to real-time adapt voice level to noise conditions, by promoting more aware vocal behaviours.

3.2 Pilot study in a Finnish open-plan office

This section deals with the preliminary application of the SEM Beta prototypes in a Finnish open-plan office. As discussed in the introductory chapter, noise generated by occupants, called Irrelevant Speech Noise (ISN), is largely known to be one of the most disturbing noise sources in open-plan offices. In this framework, a cross-sectional survey, performed in the context of the present PhD dissertation, highlighted that a high percentage of employees were willing to reduce ISN if advised to reduce voice volume by a noise monitoring system with lighting feedback. In line with this result and the needs revealed by the literature review in terms of ISN reduction (Bradley, 2003; Hongisto et al., 2016; Schlittmeier and Liebl, 2015), a challenging task of this research project is to extend the application of SEM in open-plan offices. The present pilot study is a starting point aimed at proposing a methodology to replicate in future works involving a large number of open-plan offices. In addition to the main purpose, the evaluation of the functionality of SEM prototypes and of the performance of the algorithm for office (algorithm OF) was carried out, as well as the investigation of the intensity of noise disturbance in the office. In particular, this section is aimed at preliminary contributing to answer the following **research questions:**

- How do employees experience irrelevant speech in the investigated open-plan office?
- How and whether does irrelevant speech affect the annoyance, performance, mental health and well-being, occupant behaviour during the working hours?
- How do employees perceive the presence of SEM device on their desks during their working activities, as well as its functionality in terms of variation of lighting feedback?
- Are there technical issues related to the functionality of the Beta prototype of SEM device?

3.2.1 Acoustic properties of the open-plan office

The monitoring campaign was performed at one university in Turku (Finland), in an open-plan office that was 10.8 × 8.9 × 3.1 m in size. The furniture included 12 workstations with adjustable height and equipped with lateral and frontal screens (h = 66 cm) suspended from the floor. The ceiling and the two lateral walls were treated with sound-absorbing materials, as well as the floor area. Different multipurpose rooms were available, including a back-up room for private conversations, one meeting room and one room for office equipment. The coffee area was located out of the office, thus employees were not annoyed by noise coming from conversation during the working hours. In addition, one phone booth and one chair booth were located in the office for phone conversation and for focusing on work, respectively.

Acoustic measurements were performed according to ISO 3382-2 guidelines (ISO 3382-2:2008) using an omni-directional loudspeaker. Data were recorded by

SoundBook software in unoccupied condition at the end of the working time (17:00 – 18:00). The description of the measurement set-up is not reported since it is not the goal of the present dissertation. The mean reverberation time (T_{20}) was equal to 0.4 s in unoccupied condition in the mid-frequency range (from 0.5 kHz to 1 kHz).

3.2.2 Employees sample

A total of eleven employees took part in the monitoring campaign. One employee was excluded due to the limited presence during the field experiment. The employees worked in the university administration area, in particular, in human resources and financial sectors, thus the office was open to students and university staff for consulting services. However, the meetings were conducted in dedicated areas in accordance with the office etiquette. According to the results of the first questionnaire (Q1), work tasks required periods of total concentration for the most part of the working hours, while interaction with the colleagues was required for a limited amount of time. Employees were mainly involved in test processing, writing, reading and planning work tasks, team working and telephone conversation were minor tasks. According to their self-reporting, the employees usually spent 3-5 hours or 6-8 hours for day in the office.

3.2.3 Procedure

An on-site investigation was performed before beginning the monitoring campaign in order to verify the dimensions, the acoustic conditions and the number of occupants in the office. In that occasion, a meeting with the reference employee was carried out with the aim of explaining the purposes of the project and the preliminary working plan, as well as for defining the practical activities (e.g. the timetable of the monitoring, the method for questionnaires administration). The employees' participation in the definition of the working plan were needed since the study required their active engagement in all phases of the monitoring campaign.

A consent form was delivered to each employee before beginning the monitoring, as well as the instructions about the use of the web page (described in Section 2.2.2.). In that occasion, the researcher left also the ID number of SEM devices, indeed each employee had their personal SEM on the desk and the ID number was indicated at the base of the prototype. This identification was needed for the correlation of objective and subjective data.

The monitoring campaign started around 9:15 and stopped around 15.15 for a total of 6 hours every day for the four weeks. This time band could vary according to the proper functioning of SEM devices since some issues (i.e. blocked lights or lights off) were detected during the monitoring campaign.

Every morning, the researcher placed SEM on each desk according to the ID number. At the end of the working day, the devices were taken back to be switched off and recharged every night. The daily activities were performed during the entire monitoring campaign as indicated below:

- 9:00 ---> installation of SEM devices on each desk and observation about the presence of employees
- 12:30/13:00 ---> observation about the presence of employees and restore prototypes in case of malfunctioning
- 15:15 ---> observation about the presence of employees and removing of all SEM devises.

In order to transfer data to the web page, Wi-Fi modems were installed in the office. During the monitoring, the researcher was in the surroundings of the open-plan office to cope with any problems, as well as to not influence the employees' behaviour.

3.2.4 Methodology

Objective and subjective investigations were performed over a total of 22 days. The working plan of the monitoring campaign is shown in Figure 49.

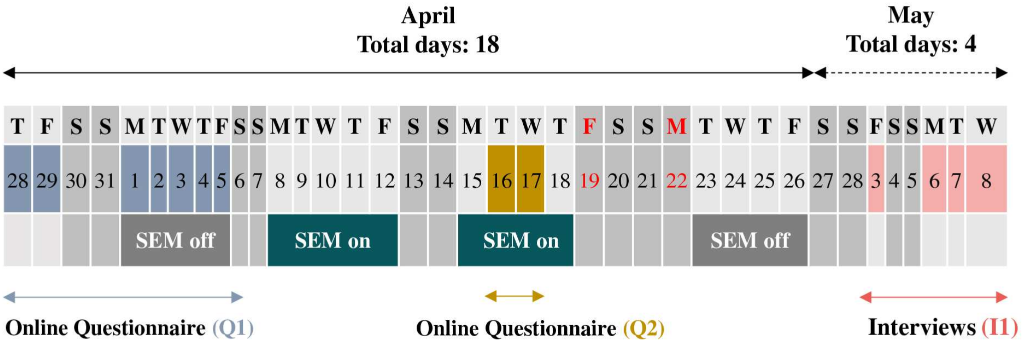

Figure 49. The working plan of the monitoring campaign in terms of objective measurements according to phase 1 (SEM off) and phase 2 (SEM on) and subjective assessments. The holiday days are indicated in red.

According to classroom monitoring campaigns, **objective measurements** of background noise levels were performed in two phases based on the absence/presence of the lighting feedback of SEM device, as follows:

o **Phase 1 (P1)** ---- > the lighting feedback was switched off in order to record typical noise levels of the open-plan office. Employees were asked to not care about the presence of SEM on their desk.

o **Phase 2 (P2)** ---- > the lighting feedback was switched on and employees were invited to control or change their behaviour.

The employees' engagement was encouraged through two external incentives, in addition to the application of SEM device. First, a paper-based communication was used as a visible reminder on the meaning of the colour of lighting feedback in terms of noise levels and behavioural action to perform (Figure 50). During the phase two, an additional paper-based communication was shown every morning with the results of the previous day in terms of percentage of green, yellow and red colours and average background noise levels for each SEM devices. These two easy paper-based communications were placed on the wall at the office entrance in order to be visible to everyone. Moreover, employees were invited to visit the web page where they could control the background noise levels in real time, as well as the time history according to the previous days.

Concerning **subjective assessments** two different methods were applied: 1) questionnaires over the entire monitoring and 2) structured interviews for each employee at the end of the field study. Figure 49 shows the periods in which the questionnaires and the interviews were carried out.

HOW CAN SEM HELP YOU IN OPEN-PLAN OFFICES?

Acceptable noise levels
Employees can CONTINUE to maintain their positive behaviour

Noise levels are slightly elevated
Employees should CONTROL their behaviour (i.e. use lower voice level)

Noise levels are too much elevated and they become annoying
Employees should CHANGE their behaviour (i.e. use lower voice level, change a room…)

Figure 49. A paper-based communication for visible remainder on the meaning of the colour of lighting feedback.

The contents of each questionnaire and of the structured interview are reported below. The complete questionnaires were in Annex C and D. The two questionnaires were prepared in Google Forms (https://www.google.com/forms/about/) and administrated through an online link distributed by the reference employee via email. It was designed according to the ethical code of the Politecnico di Torino. An accompanying letter was present at the beginning of the online questionnaire in order to explain its purposes, as well as the confidential treatment of personal data. Employees were invited to write the SEM ID number (e.g. SEM_1) in the reserved place in order to correlate the answers of both questionnaires with the objective data. In the questionnaire personal characteristics, such as name, gender, or age were not asked since the aim of the study was not to investigate the differences in subjective perception according to personal factors.

Questionnaire 1 (Q1)

The questionnaire was submitted by email before beginning the monitoring campaign. Employees were invited to reply within the first week of experiment. The questionnaire is based on the original version of the questionnaire presented in the cross-sectional survey (Section 1.3). However, some changes were carried out in order to adapt questions to the purposes of the pilot study. In particular, the three questions related to the presence of acoustic treatments in the office (Q7 - Q8) and to the willingness to use the lighting feedback for control voice volume (Q10) were excluded. Conversely, two questions were added in order to investigate the type of working tasks performed by employees and their general sensitivity on noise according to previous studies (Schutte et al., 2007). Thus, the final version was composed of a total of 9 questions grouped in three sections as follows: 1) features of work tasks, 2) noise sensitivity measured through 4 items of NoiSeQ (Schutte et al., 2007), and 3) subjective opinions on ISN and its impact on annoyance, well-being and occupant behaviour. The time to fill it in was about 10 min.

Questionnaire 2 (Q2)

The questionnaire was submitted by email at the end of the phase 2 when the lighting feedback was switched on and employees were invited to reply within the last two days while the monitoring was still ongoing. The questionnaire was composed of two sections covering the following topics: 1) working hours and days spent in the office, and 2) how SEM was experienced with active feedback. In this section several aspects were investigated, including the behavioural change, visibility of SEM, functionality of the algorithm OF according to the noise levels, frequency of visits to the web page and the results on the paper, issues found in the SEM functionality (i.e. blocked lights, no lights) and personal interest in having a device like SEM in the office. Employees were needed about 5 min to fill it in.

Interview (I1)

As shown in Figure 49, a **structured interview** was carried out in a meeting room separately for each employee in order to avoid influences and allow them to speak freely on the noise issue. The interview mainly aimed to investigate the subjective opinions reported in the questionnaires in order to collect more information. The interview covered the following topics: 1) personal behaviour during the phase 2 when the lighting feedback was switched on, 2) functionality of the algorithm OF according to the noise levels, 3) malfunction of SEM devices (i.e. blocked lights, no lights) and its influence on behavioural change, 4) general opinions on noisier offices experienced by employees, 5) opinions on the lighting visualization method and the usefulness of SEM devices, and 6) perceived acoustic conditions of the open-plan office. The duration of the interview ranged between 10 min to 15 min.

3.2.5 Key findings and considerations

Overall, the results of objective measurements showed that the open-plan office is silent, indeed the employees self-reported that they were not annoyed from the ISN. These results are in disagreement with the initial expectation and the literature review, since ISN is considered the prevalent noise source in an open-plan office occupied by more than one person. In this sense, the evaluation of the effect of the lighting feedback on behavioural change was difficult, since the employees were already aware on the proper behaviour to use in the open-plan office. They declared to be involved in an information campaign on the office etiquette when they moved in the open-plan office. According to researcher' observation, it may be hypothesised that the tendency to use low voice levels is a cultural factor in Finland. Even if the researcher noticed at the beginning of the monitoring campaign that ISN was not perceived as a problem in this office, it was decided to continue the monitoring in order to detect potentials and weaknesses in the methodology and in the functionality of SEM device. Based on these preliminary considerations, only the significant results are reported in the present PhD dissertation.

Figure 51 shows low A-weighted noise levels ($L_{Aeq,mean}$) averaged for all SEM devices and for all days of the week: from 43.1 dB(A) to 45.4 dB(A) over the entire monitoring campaign. The differences between the $L_{Aeq,mean}$ were lower over the entire period of monitoring, except when the noise levels of the second, third and fourth weeks were compared to the noise levels of the first week. The average difference of $L_{Aeq,mean}$ was 2.1 dB(A). This result could be explained according to Hawthorne effect: “subjects may behave differently, because they are aware that they are being studied” (Adair 2000; Seligman et al., 1978).

These preliminary findings led to the first consideration for the methodology improvement: 1) extending the period by one to two weeks in the first part of the experiment with the lighting feedback switched off, and 2) the introduction of one week after the phase 2 can be useful to better understand the trend in noise levels over the weeks.

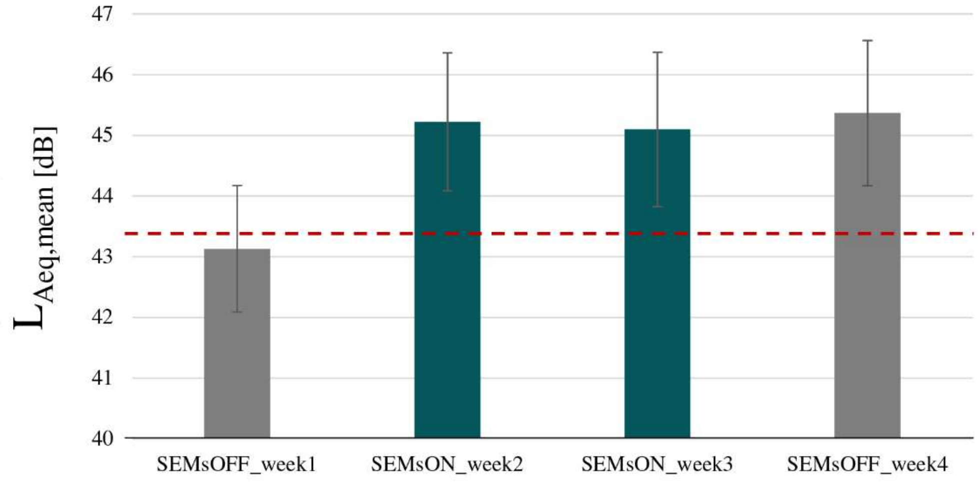

Figure 50. The trend of A-weighted noise levels ($L_{Aeq,mean}$), averaged for all SEM devices and for all days, over the weeks of the monitoring campaign.

Concerning the results of Q1, Figure 52 confirms that most of the employees were not annoyed by ISN. A very low percentage of subjects (27%) were fairly or extremely annoyed by it. Therefore, it is important to note that a little number of employees were sometimes annoyed by ISN, despite the general quietness of the open-plan office. As emerged in the interviews, the annoyance was generated by speech from colleagues set in the nearest workstation (less than 2 m away). This result is in accordance with (Haapakangas et al., 2014; Hongisto et al., 2016): they found that the distraction and annoyance generated by nearby speech cannot be sufficiently decreased through an accurate room acoustic design characterized by the use of sound absorption, high screens and sound masking systems. Noisy door is perceived as the most disturbing factor, as well as the entrances and exits of people, as emerged in the interviews.

In accordance with the results of cross-sectional survey, loss of concentration was self-reported as a main feeling when ISN was present in the open-plan office. The main strategy used by 36% of employees to cope with the chatting noise is the working spaces change (Figure 52). It may be hypothesised that the presence of different multipurpose rooms allowed employees to use other environments.

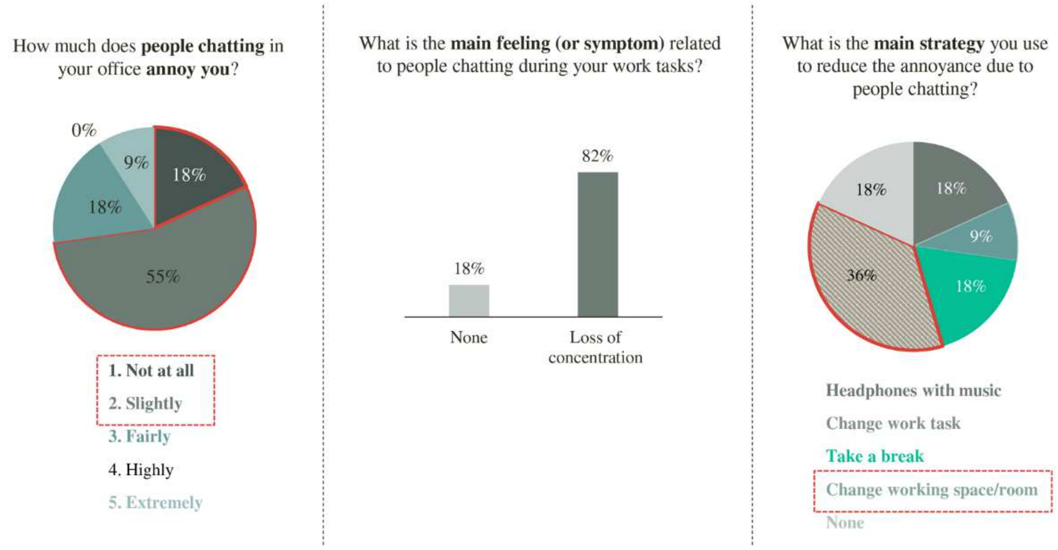

Figure 51. The percentage of responses related to noise annoyance, consequences of ISN and personal strategies to cope with the noise levels.

Concerning the results of Q2, Figure 52 shows that the behaviour of employees did not change according to the presence of the lighting feedback. This is not unexpected, since employees were already aware on the proper behaviour to adopt in open-plan office, as mentioned before.

The majority of employees (64%) declared that they noticed the malfunction of SEM devices, as well as that they did not agree with the changing of colours feedback according to speech and noise conditions. The graphs are not reported here since these responses were referred to yes/no question with option "Don't know" (Annex E). Employees did not choose this option. As indicated by employees during the interviews, the malfunction of SEM devices did not influence their behaviour because they did not care much about the presence of the lighting feedback. While the majority of employees declared that the lighting feedback is too sensible and became red for accidental noise, such as sneezing, keys resting on the desk and chatting of people around.

Figure 52. The percentage of responses related to behavioural change generated by the presence of SEM device.

According to objective data, the malfunction of SEM devices was estimated of 19% according to the ratio between time of proper functionality and total duration of the monitoring. Thus, this issue did not influence the objective results in terms of noise levels. The problems of the functionality of the Beta prototypes were related to operating system and have already been solved through an upgrade towards the new operating system.

The paper on wall with the results related to the previous day was checked by 45% of employees almost or every day, conversely the web page was not much visited (Figure 54). However, it is difficult to evaluate the usefulness of the web page from this pilot study since employees were not motivated to change their behaviour as the ISN was not a problem for them. All employees declared that SEM devices were located in the good position on the desk and the lighting feedback was an efficient and easy way to show the noise levels.

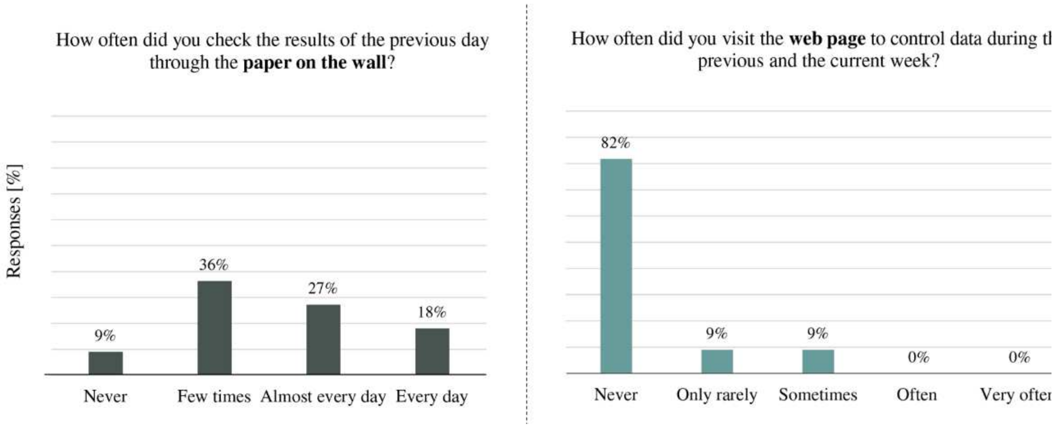

Figure 53. The percentage of responses related to the visualization of paper-based communication and web-page for controlling the results.

3.2.6 Limitations and proposal for future investigations

The present study is a starting point for future investigations, thus outcome and methodology evaluation are useful to acknowledge some limitations, that are summarized as follows:

- The absence of ISN led to poorly significant results, in terms of the usefulness of SEM device and indication about behavioural change. Indeed, employees were not encouraged to follow the lighting feedback because they did not perceive the noise issue related to behaviour of colleagues.
- The duration of the monitoring should be extended to better understand if subjects tend to change behaviour at the beginning when the lighting feedback of switched on because they were aware to be studied. Moreover, the extension in the duration can be useful to administrate the first questionnaire and to analyse data before the beginning of the monitoring campaign in order to know the intensity of noise problem.
- The algorithm seems to be too sensible to accidental noise levels according to employees' perception. However, a large number of different types of open-plan offices should be involved for gathering more information about how employees perceive the variation of the lighting feedback according to the sound levels. In particular, noisier offices are needed for future investigation.
- An issue in operating system of SEM devices led to lighting blocks. However, the little interest of employees in the use of the lighting feedback made this issue poorly perceived in this present pilot study. The good functionality of the Beta prototype is needed for the future monitoring campaign in order to not reduce the motivation of employees in the use of the lighting feedback to perform proactive behaviour.

Future monitoring campaigns will be carried out in collaboration with the Prevention and Protection Services office of the Politecnico di Torino with the aim of improving acoustic conditions of office and better understanding how employees perceive the presence of SEM on their desks during their working activities. Moreover, future work aims to find out any possible improvements in view of reaching the development of complete and qualified system for large-scale application.

PART 4

Conclusion

Overview

The present PhD dissertation tackled some challenges in the field of occupant engagement and promotion of more aware behaviours to reduce noise levels in working environments. **This chapter aims to sum up the findings, following the research questions detailed in section “The dissertation at a glance”.** Future works are needed to better understand how occupants interact with the external incentives, such as ICT-based solutions and lighting feedback systems, and to evaluate their effectiveness on a long-term behavioural change. At the end of this chapter **future prospective** are described to highlight the themes that should be addressed based on the lines of this PhD dissertation.

4.1. Answers to initial research questions

At the end of this PhD research project some conclusions on the effectiveness of SEM device in terms of noise reduction and behavioural changes can be made, thus the answers to initial research questions are summarized below.

Research question #1: How do employees evaluate the **effects of irrelevant speech noise** on annoyance, performance, mental health and well-being, and occupant behaviour in **shared and open-plan offices**?

Research question #2: Are there **relationships between perceived noise annoyance**, **personal characteristics** (i.e. age, gender and professional sector) and **office characteristics** (i.e. city, number of people in the office and room acoustic design)?

These research questions were addressed in **Chapter 1** and in the reference paper: *"A cross-sectional survey on the impact of irrelevant speech noise on annoyance, mental health and well-being, performance and occupants behavior in shared and open-plan offices"* (Di Blasio et al., 2019).

A cross-sectional survey was performed to provide new knowledge about the impact of Irrelevant Speech Noise (ISN) in two types of offices: shared (2–5 occupants) and open-plan (+5 occupants) offices. A total of 1078 subjects of different office environments in Italy were involved.

The key findings showed that ISN is more annoying in open-plan (O) than in shared offices (S), as confirmed by mean values (O: Mn = 3.07; S: Mn = 2.54) and the significant difference according to MWU test ($p < 0.001$, V = 0.25). Similarly, employees are more frequently interrupted by ISN in open-plan offices than employees in shared offices (O: Mn = 3.44; S: Mn = 3.06, $p < 0.001$, V = 0.20) and, as a consequence, their working performance is lowered. ISN also impacts the health of employees: a significant increase in physical symptoms is perceived by occupants working in open-plan offices, compared to occupants working in shared spaces ($p < 0.05$, $h = 0.45$). In particular, 6% and 4% of the employees self-estimated mental illness, such as stress, as main symptom of ISN. The differences in the behavioural strategies used by employees to cope with ISN, such as the use of technological tools, the adaptive behaviour and asking colleagues to reduce their voice levels, are not significant between the two office sizes.

Noise annoyance is significantly affected by gender and office characteristics in terms of city location, number of people in office and acoustic treatments. In particular, women are more annoyed than men in open-plan offices (OR = 1.79, 95% CI: 1.19–2.70), while no differences between gender are found for shared offices. The employees working in southern cities are more annoyed than their counterparts working in northern ones in both shared (OR = 2.52, 95% CI: 1.65–3.89) and open-plan offices (OR = 2.26, 95% CI: 1.18–4.33). Furthermore, having more than 20 occupants in an office make being annoyed by ISN more probable than having from 6 to 20 occupants (OR = 8.70, 95% CI: 1.11-68.20). The employees of shared offices are less annoyed by ISN when offices are not acoustically treated (OR = 2.17, 95% CI: 1.11–4.22), while they are less annoyed when the open-plan office is acoustically treated (OR = 1.70, 95% CI: 1.06–2.72).

With respect to the use of the lighting feedback systems, 62% and 72% employees stated they are willing to reduce irrelevant speech noise in shared and open-plan offices, respectively, if these systems are able to advise them to reduce voice volume. Therefore, lighting feedback systems such as SEM devices could be accepted by employees in office where irrelevant speech noise is perceived as a problem.

Research question #3: Which **technical solutions** can be applied for **solving weakness and shortcomings of the Alpha prototype** and **existing devices**, as well as for **generating a scalable, accurate, adaptable and customizable prototype** in view of the final implementation of the system?

This research question was addressed in **Chapter 2.**

A Beta prototype was developed to be representative of a device ready for productization and large-scale applications. Thus, technical solutions were selected to respond to the following attributes: portability, time- and cost-efficiency of manufacturing and assembling process, flexibility and visibility of the product.

As a result of the technical options, the SEM Beta version is a small and light table device able to ensure an easy portability encouraging the large-scale adoption in real environments or on-the-fly repositioning based on actual needs. For example, the Beta prototype can be used efficiently in school classrooms with tables organized in small group in order to solve the issue of poor visibility. Furthermore, there is an entire independence between casing and hardware/software components, which is an asset to plan a flexible and customizable product design. Finally, the engineered electrical components have been designed to exhibit enhanced signal processing capabilities and to promote a possible future mass production.

Research question #4: What is the **accuracy of Beta version of SEM prototype** in measurement of reliable decibel levels in real environments compared to the 1-class Sound Level Meter?

This research question was addressed in **Chapter 2.**

A calibration by comparison was performed in order to make SEM prototypes able to measure reliable Sound Pressure Levels (SPL) according to a class 1 Sound Level Meter. As a result of this procedure, a Global Correction Filter (GCF) was developed to be applied in the signal processing. A field validation in a real shared office during the working hours was carried out in order to evaluate whether SEM prototypes with the GCF can measure accurate sound levels. Provided the main purpose of this device, that is control noise generated by human speech, the results show that Beta prototypes measure reliable decibel levels in the typical speech spectrum (125-2000 Hz), with a similar SPL trends over frequency compared to Sound Level Meter. Further acoustic tests prescribed by 2013 IEC specification, such as self-generating noise and long-term stability, will be performed when the prototype will be in a more advanced stage of production.

Based on the emerging gaps in the application of the lighting feedback systems and in detailed indication on their effects on behavioural change and its fulfilment on a long-term, the field application of SEM devices is aimed at contributing to new knowledge in this research theme.

Regarding field application in school classrooms, the SEM Alpha version was applied in 13 classes of a primary school in Turin (Italy) over 3-scholastic years with the aim to reach several research questions.

All following research questions were addressed in **Chapter 3** – *Section 3.1.1. Monitoring of background noise levels* – *Section 3.1.5. Results and discussion: monitoring of background noise levels*

Research question #5: Does **SEM device** affect **the background noise levels generated by pupils**?

Research question #6: Can **independent variables**, such as *teacher*, *time-band, number of pupils, day of week* and *class*, **significantly affect the background noise levels** in the two lighting conditions?

The results of two-factors analysis of variance (ANOVA) showed that *teacher*, *time-band, day of week* and *class* were significant fixed factors that affect the background noise levels. The effect of lighting feedback was not significant on background noise levels, except in a first-grade class of the third monitoring campaign. Some degree of interactions emerged between the effect of these factors and the effect of the lighting feedback on the dependent variable ($L_{A90,mean}$), even if only one interaction between *day of week* and the lighting feedback was statistically significant.

With respect to the analysis where all the fixed factors (independent variables) were controlled, a significant decrease of background noise levels when the lighting feedback of SEM devices was switched on was obtained for a total of 51% pairs of independent lessons (improvements). In particular, the activation of the lighting feedback led to an average decrease of 3.2 dB(A), 2.2 dB(A) and 3.3 dB(A) in the first, second and third monitoring campaigns, respectively. These decreases emerged when the starting noise conditions were worse, i.e. the background noise levels are highest in the absence of the lighting feedback.

In the other pairs of independent lessons (49%), background noise levels increased or did not significantly decrease in the presence of the lighting feedback (no improvements). The average increase of $L_{A90,mean}$ values was about 1.6 dB, 1.9 dB and 2.5 dB in the first, second and third monitoring campaigns, respectively. However, these increases were lower compared to the decreases of background noise levels when the lighting feedback was switched on. Several reasons may be hypothesised for this result: for example pupils paid smaller attention towards the lighting feedback because the activities required more interaction between them and teachers. The background noise levels were not extremely annoying to require a behavioural change. Moreover, the engagement of teachers aimed at motivating pupils to follow the lighting feedback was lower. Overall, the effect of SEM devices in terms of background noise levels reduction was higher in the first monitoring campaign, follow by the third monitoring ones. Conversely, a lower improvement in terms of noise reduction was generally obtained in the second monitoring campaign.

Research question #7: Can the **motivational methods** based on constant feedback and/or game-based challenge encourage pupils towards a **long-term behavioural change**?

Motivational methods based on constant feedback and/or game-based challenge were introduced in the second and third monitoring campaigns, in addition to SEM technology. The second monitoring campaign suffered from the limitation related to the small samples size, thus the significance of the effect of the motivational method could be only evaluated in the third monitoring campaign. The phase 2 of the monitoring, i.e. the phase with the lighting feedback switched on, were divided into three periods. A decreasing trend besides the first period of P2 emerged for the greater number of classes. In particular, significant differences in the averaged $L_{A90,mean}$ values were found in the class 1I between the first and the last periods of phase 2 ($p = 0.002$, $d = 1.02$), equal to 2.7 dB(A) , and between the middle and last periods, equal to 2.0 dB(A) ($p = 0.010$, $d = 1.02$). Similarly, a significant difference of 1.8 dB(A) was obtained between the first and the last periods in the class 4O ($p = 0.004$, $d = 1.78$). These results seem to suggest that the motivational method, i.e. the constant feedback provided by the researchers on the results obtained during the entire week, led to a fulfilment over a long-term period in proactive behaviour of pupils in two classes in the cases where the lighting feedback was found effective. However, future works are needed to verify the presence of the same trend in other classes and to improve the reliability of the results.

Research question #8: How do teachers assess the **acoustic quality of classrooms**? How do they perceive the presence of **SEM device** as an **educational tool** in classrooms also in relation to pupils' behaviour?

A questionnaire was performed during the third monitoring campaign in order to evaluate how the acoustic environment was perceived by teachers and to gather information about the usefulness of the lighting feedback. The findings of the subjective investigation cannot be generalized due to the small sample size (8 teachers), thus they are not further discussed here. The explorative results are reported in Section 3.1.5.5. to document the study, to better understand some objective results and to highlight differences between teachers and classes in the assessments of classroom acoustics and the use of SEM device as an educational tool.

Regarding the use of the lighting feedback system related to monitoring of teachers' vocal behaviour, a pilot study was carried out within the third monitoring campaign in four school classrooms, as a starting point for proposing a methodology for future investigation.

All the following research questions were addressed in **Chapter 3 –** *Section 3.1.2. Pilot study: long-term monitoring of teachers' vocal behaviour* **–** *Section 3.1.6. Results and discussion: pilot study on long-term monitoring of teachers' vocal behaviour.*

Research question #9: Do the **teachers' voice levels** decrease when the lighting feedback of SEM devices is switched on in classrooms?

The long-term voice monitoring performed in classrooms using the portable vocal analyzer showed a lower tendency in raising voice levels in relation to background noise levels when the lighting feedback of SEM was switched on. For example, a lower increase in the speech level of 0.43 dB compared to 0.53 dB per 1 dB (A) was found in a range of background noise between 45 dB(A) to 78 dB(A).

Research question #10: Is there a **significant difference** in terms of **voice levels** and **background noise levels** when **SEM devices are switched on**, independently from the subjects?

Research question #11: How does **SEM device** affect the **vocal effort of each teacher** and the **background noise levels**, class-by-class?

Contrary to the hypothesis of the present study, the average values of the voice parameter were slightly higher in the presence of the lighting feedback (66.8 dB) compared to voice monitorings without the lighting feedback (66.5 dB). Similarly, noise levels were on average 53.3 dB(A) and 53.8 dB(A) with and without the lighting feedback, respectively.

Considering the effect of SEM devices class-by-class, two teachers of second and fourth grade classes significantly decrease their vocal effort in relation with the significant reduction of background noise levels. However, the effect sizes demonstrate that only the second-grade class teacher is moderately affected by the presence of the lighting feedback of SEM devices. In accordance with this result, this teacher perceived the effectiveness of SEM device in terms of noise reduction and the overall high decrease of noise levels, equal to 3.6 dB(A), was found when the lighting feedback was switched on during the third monitoring campaign.

Research question #12: How do teachers perceive their **vocal status, noise condition** and **voice intensity** with and without SEM devices?

According to the timesheet filled in by teachers at the end of each monitoring, they self-reported mild or low voice problems during the long-term monitorings in absence and in presence of the lighting feedback. The intensity of noise was perceived as higher during the long-term monitoring when the lighting feedback of SEM devices was switched off. Teachers perceived a raised voice levels during the lessons independently of the lighting feedback of SEM devices.

It is important to highlight that the small sample size and the little number of long-term monitorings of teachers' vocal behaviour led to the low power of the aforementioned conclusions.

The pilot study on the application of SEM device in open-plan offices is a starting point, indeed the project is still on-going with the aim to involve a large number of offices that differ in their characteristics (i.e. room acoustics, location, number of occupants) and type of work.

All the following research questions were addressed in **Chapter 3 –** *Section 3.2. Pilot study in a Finnish open-plan office.*

Research question #13: How do **employees experience irrelevant speech** in the investigated open-plan office?

Research question #14: How and whether does **irrelevant speech** affect the **annoyance, performance, mental health and well-being, occupant behaviour** during the working hours?

As a result of objective measurements, low noise levels were recorded over the weeks, between 43.1 dB(A) and 45.4 dB(A), demonstrating that the selected open-plan office was silent. Indeed, the problem of irrelevant speech noise was rarely perceived, despite the office was occupied by twelve employees. Noisy door was perceived as the most disturbing factor, as well as the entrances and exits of people.

In general, employees were not affected by the presence of the lighting feedback. However, some of them were sometimes annoyed by irrelevant speech noise, despite the general quietness of the open-plan office. This means that the perception of annoyance is a subjective phenomenon, which can be influenced by cultural factors, different preferences, priorities and working habits.

The lack of attention towards SEM devices was confirmed by no significant differences in averaged A-weighted equivalent noise levels between the weeks with and without the lighting feedback, except in the first one. Indeed, significant lower noise levels were found in the first week compared to the other three weeks of the monitoring campaign, with an average difference of 2.1 dB(A). This result is probably caused by the Hawthorne effect, which indicates that "subjects may behave differently, because they are aware that they are being studied."

Research question #15: How do **employees perceive** the **presence of SEM device** on their desks during their working activities, as well as its functionality in terms of variation of lighting feedback?

The majority of employees (64%) did not agree with the changing of colours feedback according to speech and noise conditions because they declared that the lighting feedback is too sensible becoming red for accidental noise, such as sneezing, keys resting on the desk and chatting of people around. However, the idea of the coloured lighting feedback used on each desk was considered an efficient and easy way to show the noise levels, and the largest number of employees would use SEM devices in noisy spaces.

Since the irrelevant speech noise was not a problem in this open-plan office, further field studies are required to gain a clearer picture on the way the users interact with SEM and to define a robust algorithm based on subjective perception.

Research question #16: Are there **technical issues** related to the **functionality of the Beta prototype** of SEM device?

Objective and subjective data highlighted the malfunctioning of SEM devices that generated lighting blocks. In general, the problems of the functionality of the Beta prototypes were related to operating system and they have already been solved now through upgrade towards the new operating system.

4.2 Future activities

The introduction of external incentives aimed at motivating occupants' engagement and aware behavioural change on a long-term is a challenging task that can require great effort due to cultural factors, different preferences, priorities and habits, which vary from one environment to the other one.

This PhD project aimed at answering some research questions; nonetheless, during the research new questions have been opened and, thus, future work is necessary to improve and increase knowledge. First, the closest perspective work resulting from this study is the focus on the large-scale application of SEM Beta version in different shared and open-plan offices, by applying the methodology proposed in the context of this dissertation. In particular, the future work aims at investigating how users interact with SEM devices in order to reach the proper algorithm.

Since the engagement of occupants in reduction of noise generated by human speech is not only a technological challenge, a user-centered approach could be used for defining several interaction scenarios with SEM device to better understand how the external casing could be customized. Moreover, in addition to the lighting feedback, the development of further external incentives should be designed through the participation of employees and a better investigation on the weaknesses and potentials emerged by the existing solutions.

Concerning the application of SEM device in school classrooms, the new challenge is to apply the lighting feedback in primary classrooms attended by pupils with hearing impairments. A different school will be involved in this future work, and a multidisciplinary approach and collaborations between experts on acoustic environmental quality, pedagogy and educational methods will be adopted in order to solve the limitations raised form the present PhD research. The perception of pupils in relation to the lighting feedback will be also investigated.

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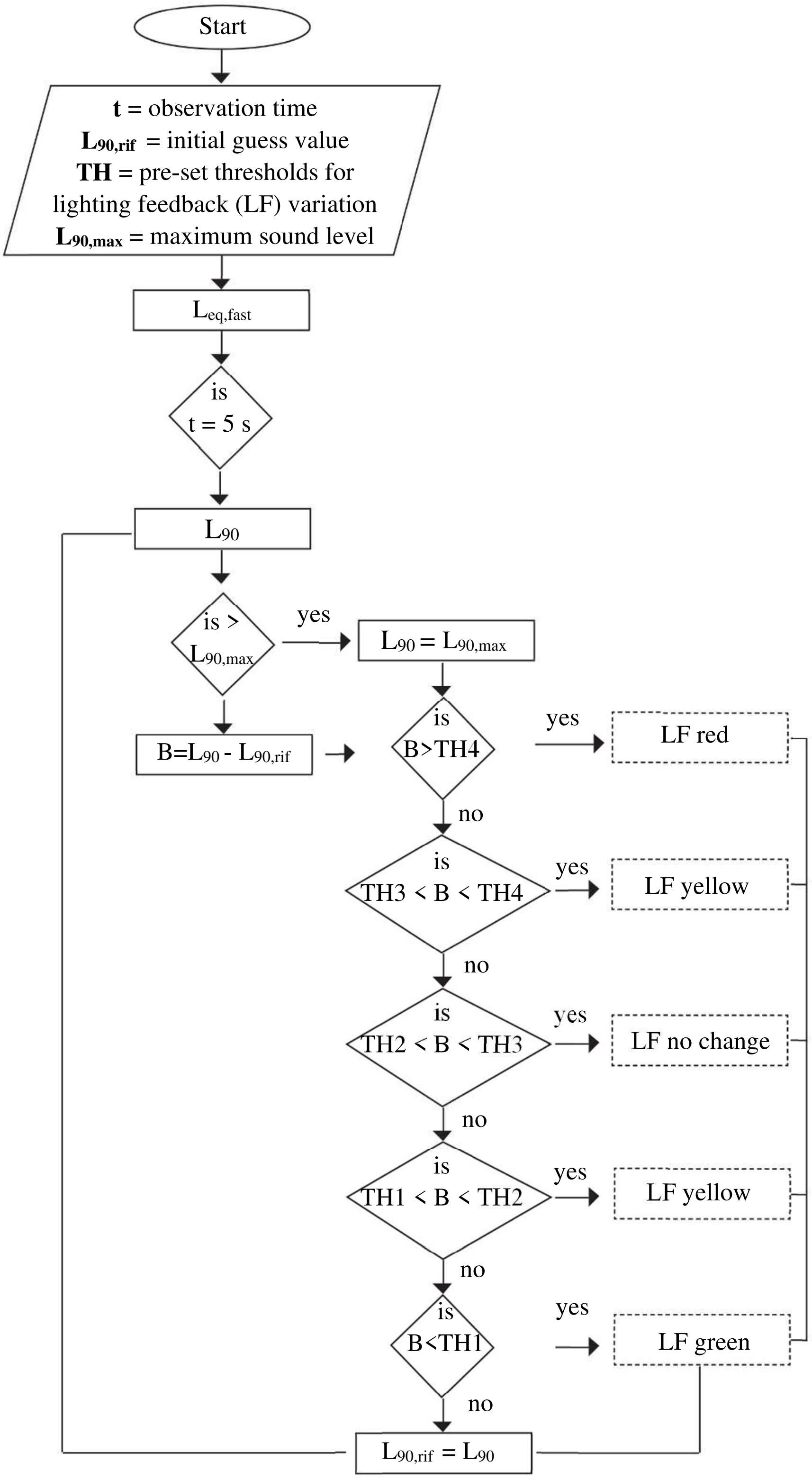
Appendix A

Flowchart Algorithm for classrooms



Appendix B

Questionnaire

EVALUATION ON ACOUSTIC QUALITY OF CLASSROOM AND ON THE USE OF THE DEVICE SEM (Speech and Sound SEMaphore) DURING TEACHING ACTIVITIES

Date: __________ Time: ___________

Class: ____________________ Name: ____

This questionnaire aims at assessing the acoustic quality of the classroom where you are used to teach. In particular, we are interested in the impact of noise levels and reverberation condition that you perceive on the voice levels you have to maintain, on your comprehension of pupils' words, and your health and well-being during the teaching activities. Moreover, we invite you to evaluate your satisfaction in the use of SEM devices as educational tools.

We ask you to fill in the survey based on your personal opinions as accurately as possible. There are neither right nor wrong answers, thus feel free to share your opinions.

Thank you for your collaboration.

GENERAL INFORMATION ABOUT YOU

(1) Gender: ☐ M ☐ F

(2) Age: ________

(3) Is Italian your mother tongue? ☐ Yes ☐ No

(4) Do you smoke? ☐ Yes ☐ No

(5) Is the street (or square or courtyard) where your classroom faces noisy? ☐ Yes ☐ No

(6) How many years have you been teaching for?

Less than 6	From 7 to 12	From 13 to 18	From 19 to 21	More than 21
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

(7) Which subjects do you teach?

Italian ☐
Math ☐
Physical education ☐
Other______________________________ ☐

(8) Which is your common position in the classroom during the teaching activities?

Sitting at the desk ☐
Standing at the desk ☐
Sitting among students ☐
Standing among students ☐
Other______________________________ ☐

ACOUSTIC QUALITY OF CLASSROOM

(9) Which is the influence of acoustic conditions on the quality of teaching within the classroom?

Very little 1	2	3	4	A great deal 5
☐	☐	☐	☐	☐

(10) Which is the intensity (volume) of average noise in the classroom, compared to the unoccupied room and empty school at the beginning of the day:

Very low   Very high
1 ☐   2 ☐   3 ☐   4 ☐   5 ☐

(11) Indicate the noise intensity, the degree of disturbance and occurrence frequency of the following noise sources in the classroom, compared to the unoccupied room and empty school at the beginning of the day:

			Very low				Very high
			1	2	3	4	5
(a)	Students talking						
		Intensity	☐	☐	☐	☐	☐
		Disturbance	☐	☐	☐	☐	☐
		Frequency	☐	☐	☐	☐	☐
(b)	Students moving		☐	☐	☐	☐	☐
		Intensity	☐	☐	☐	☐	☐
		Disturbance	☐	☐	☐	☐	☐
		Frequency	☐	☐	☐	☐	☐
(c)	Students talking in the adjacent classrooms						
		Intensity	☐	☐	☐	☐	☐
		Disturbance	☐	☐	☐	☐	☐
		Frequency	☐	☐	☐	☐	☐
(d)	Students moving in the adjacent classrooms (moving of chairs and desks)						
		Intensity	☐	☐	☐	☐	☐
		Disturbance	☐	☐	☐	☐	☐
		Frequency	☐	☐	☐	☐	☐
(e)	Students talking and moving in the corridor						
		Intensity	☐	☐	☐	☐	☐
		Disturbance	☐	☐	☐	☐	☐
		Frequency	☐	☐	☐	☐	☐
(f)	Traffic outside the building						
		Intensity	☐	☐	☐	☐	☐
		Disturbance	☐	☐	☐	☐	☐
		Frequency	☐	☐	☐	☐	☐
(g)	Sounds inside the building (outdoor market, school yard, etc…), except traffic outside the building						
		Intensity	☐	☐	☐	☐	☐
		Disturbance	☐	☐	☐	☐	☐
		Frequency	☐	☐	☐	☐	☐
(h)	Sounds in the building, but outside the class (coffee machine, lift, etc..), except noise from the students talking						
		Intensity	☐	☐	☐	☐	☐
		Disturbance	☐	☐	☐	☐	☐
		Frequency	☐	☐	☐	☐	☐

(12) Evaluate the reverberation of the sounds and the voices in classroom, compared to the condition without reverberation that you find outdoor

the sounds are very dry (no echos like outdoor)				The sounds are not very dry
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

(13) How well do you understand the words spoken by pupils set at the tables when you are at the desk?

I don't understand anything				I understand all
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

(14) Evaluate your vocal effort during the lessons, compared to the vocal effort you would have in a condition of generic conversation without noise and reverberation

Very low				Very raised
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

(15) The classroom has a good acoustics to hold lessons

I agree				I don't agree
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

(16) Indicate how often the classroom acoustics causes the following consequences:

		Never				Very often
		1	2	3	4	5
(a)	Speech comprehension	☐	☐	☐	☐	☐
(b)	Loss of concentration	☐	☐	☐	☐	☐
(c)	Headache	☐	☐	☐	☐	☐
(d)	Sore throat	☐	☐	☐	☐	☐
(e)	Aphonia	☐	☐	☐	☐	☐
(f)	Hoarseness	☐	☐	☐	☐	☐
(g)	Neck stiffness	☐	☐	☐	☐	☐
(h)	General sickness	☐	☐	☐	☐	☐
(i)	Other (..................…………………..….)	☐	☐	☐	☐	☐

(17) Describe here the strategies you adopt to reduce vocal effort and help pupils to better understand your voice

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GENERAL OPINIONS ABOUT SEM DEVICE

(18) Which is your satisfaction level with the SEM device regarding the reduction of noise generated by pupils for the following activities?

		Not at all 1	Slightly 2	Fairly 3	Highly 4	Extremely 5
(a)	Frontal lesson	☐	☐	☐	☐	☐
(b)	Lunch	☐	☐	☐	☐	☐
(c)	Break time	☐	☐	☐	☐	☐
(d)	Group activity	☐	☐	☐	☐	☐
(e)	Other (..................…………………..….)	☐	☐	☐	☐	☐

(19) Do you consider SEM devices useful to reduce your vocal effort and to help pupils to better understand your voice?

Yes ☐
No ☐

Motivate your answer

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(20) Evaluate how much pupils paid attention to the change of the lighting feedback of SEM devices in the following activities:

		Not at all 1	Slightly 2	Fairly 3	Highly 4	Extremely 5
(a)	Frontal lesson	☐	☐	☐	☐	☐
(b)	Lunch	☐	☐	☐	☐	☐
(c)	Break time	☐	☐	☐	☐	☐
(d)	Group activity	☐	☐	☐	☐	☐
(i)	Other (..................…………………..….)	☐	☐	☐	☐	☐

(21) Evaluate how much pupils became more responsible in changing their voice levels over the entire period in which SEM devices were switched on?

Not at all	Slightly	Fairly	Highly	Extremely
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

(22) In your opinion, is the communication of the green, yellow and red lights by researcher each week an effective method to motivate pupils constantly?

Yes ☐
No ☐

Motivate your answer

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\---
\---

(23) Evaluate your interest in adopting SEM devices to reduce noise generated by pupils

Not at all interested	Slightly interested	Fairly interested	Interested	Extremely Interested
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

(24) Add here free, additional opinions related to SEM devices

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Appendix C

Timesheet

Please do not touch the voice sensor during the monitoring

EVALUATION OF THE VOCAL EFFORT RELATED TO YOUR LAST LESSON

Date ______________School______________________ Classroom or school section__________________

Name ____

Surname ____

1. Sex F M
2. Age ____
3. Years of teaching experience ____
4. Subject(s) taught ____
5. Type of lesson (please mark the best matching option):

   o traditional lesson (plenary lesson)

   o half traditional, half group lesson

   o group lesson

Please draw a cross on the line to position your answer:

6. Evaluate your actual voice status compared to the beginning of your working day:

   No voice problems Severe voice problems

   |____|

7. Evaluate the noise level in the classroom compared to an empty classroom at the beginning of the day:

   Very low Very high

   |____|

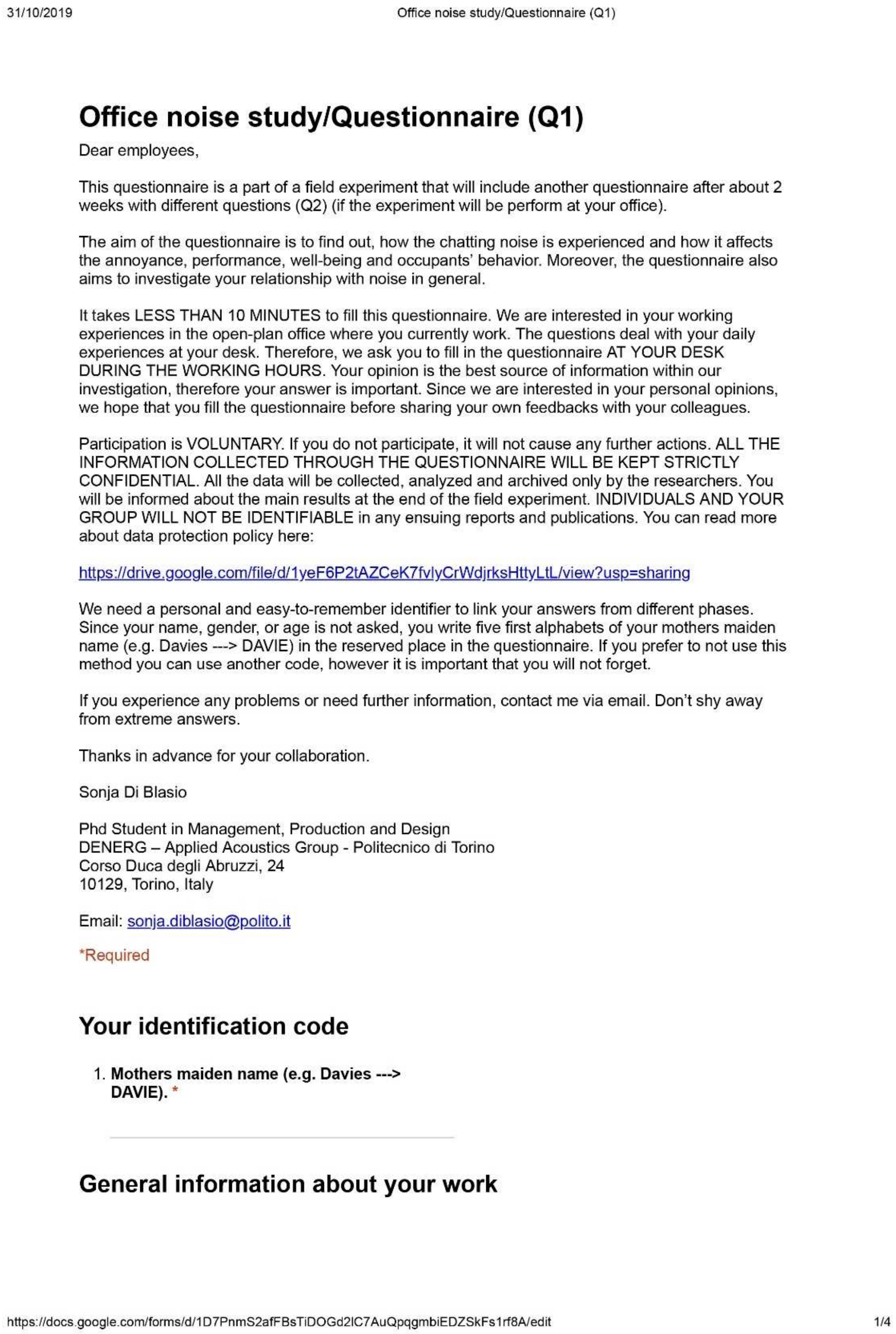
8. I had to raise my voice in order to be heard in the classroom, thus achieving a voice level higher than in absence of noise and reverberation (echo):

   I completely agree I completely disagree

   |____|

Appendix D

Open-plan office: Q1



Office noise study/Questionnaire (Q1)

Dear employees,

This questionnaire is a part of a field experiment that will include another questionnaire after about 2 weeks with different questions (Q2) (if the experiment will be perform at your office).

The aim of the questionnaire is to find out, how the chatting noise is experienced and how it affects the annoyance, performance, well-being and occupants' behavior. Moreover, the questionnaire also aims to investigate your relationship with noise in general.

It takes LESS THAN 10 MINUTES to fill this questionnaire. We are interested in your working experiences in the open-plan office where you currently work. The questions deal with your daily experiences at your desk. Therefore, we ask you to fill in the questionnaire AT YOUR DESK DURING THE WORKING HOURS. Your opinion is the best source of information within our investigation, therefore your answer is important. Since we are interested in your personal opinions, we hope that you fill the questionnaire before sharing your own feedbacks with your colleagues.

Participation is VOLUNTARY. If you do not participate, it will not cause any further actions. ALL THE INFORMATION COLLECTED THROUGH THE QUESTIONNAIRE WILL BE KEPT STRICTLY CONFIDENTIAL. All the data will be collected, analyzed and archived only by the researchers. You will be informed about the main results at the end of the field experiment. INDIVIDUALS AND YOUR GROUP WILL NOT BE IDENTIFIABLE in any ensuing reports and publications. You can read more about data protection policy here:

https://drive.google.com/file/d/1yeF6P2tAZCeK7fvlyCrWdjrksHttyLtL/view?usp=sharing

We need a personal and easy-to-remember identifier to link your answers from different phases. Since your name, gender, or age is not asked, you write five first alphabets of your mothers maiden name (e.g. Davies ---> DAVIE) in the reserved place in the questionnaire. If you prefer to not use this method you can use another code, however it is important that you will not forget.

If you experience any problems or need further information, contact me via email. Don't shy away from extreme answers.

Thanks in advance for your collaboration.

Sonja Di Blasio

Phd Student in Management, Production and Design
DENERG – Applied Acoustics Group - Politecnico di Torino
Corso Duca degli Abruzzi, 24
10129, Torino, Italy

Email: sonja.diblasio@polito.it

*Required

Your identification code

1. **Mothers maiden name (e.g. Davies ---> DAVIE).** *

General information about your work

2. **How often does your job involve periods of total concentration?**

Mark only one oval.

○ Never
○ Only rarely
○ Sometimes
○ Often
○ Very often

3. **How often does your job require interaction with other employees?**

Mark only one oval.

○ Never
○ Only rarely
○ Sometimes
○ Often
○ Very often

4. **How often do you perform the following tasks during your typical working day?**

Mark only one oval per row.

	Never	Only rarely	Sometimes	Often	Very often
Text processing, writing, reading	○	○	○	○	○
Mathematical tasks, billing, statistics	○	○	○	○	○
Planning or creative work, programming	○	○	○	○	○
Team working	○	○	○	○	○
Telephone conversations	○	○	○	○	○
Practical organisation (e.g. copying, filling-in forms, administrative tasks)	○	○	○	○	○

Your relationship with noise in general at work

5. **How do you find the following statements?**

Tick all that apply.

	Strongly disagree	Slightly disagree	Slightly agree	Strongly agree
When people around me are noisy I don't get on with my work	☐	☐	☐	☐
I need peace and quiet to do difficult work	☐	☐	☐	☐
I need quiet surroundings to be able to work on new tasks	☐	☐	☐	☐
My performance is much worse in noisy places	☐	☐	☐	☐

Personal opinions on chatting noise inside your whole office space

N.B. Chatting noise is the noise that is generated from conversations between colleagues, telephone calls and laughter.

6. **How much does people chatting in your office annoy you?**
Mark only one oval.

○ Not at all
○ Slightly
○ Fairly
○ Highly
○ Extremely

7. **What is the main feeling (or symptom) related to people chatting during your work tasks?**
Mark only one oval.

○ Anger
○ Loss of motivation
○ Tiredness and overstrain
○ Stress
○ Loss of concentration
○ Negative feelings such as feeling displeased
○ Negative feelings towards other colleagues or co-workers
○ Headache
○ None
○ Other: ______________________

8. **How do you find the following statements?**
Tick all that apply.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
People chatting around often interrupts me during my work tasks	☐	☐	☐	☐	☐
People chatting does not allow me to work as much as I would like to	☐	☐	☐	☐	☐
People chatting around significantly reduce my work performance	☐	☐	☐	☐	☐
People chatting compromises the harmony of the entire office	☐	☐	☐	☐	☐

9. **What is the main strategy you use to reduce the annoyance due to people chatting?**

Mark only one oval.

○ Change working space/room
○ Headphones with music
○ Noise cancelling headphones
○ Ask people to reduce voice
○ Change work task
○ Work from home
○ Take a break
○ Close the office door
○ None
○ Other: ______

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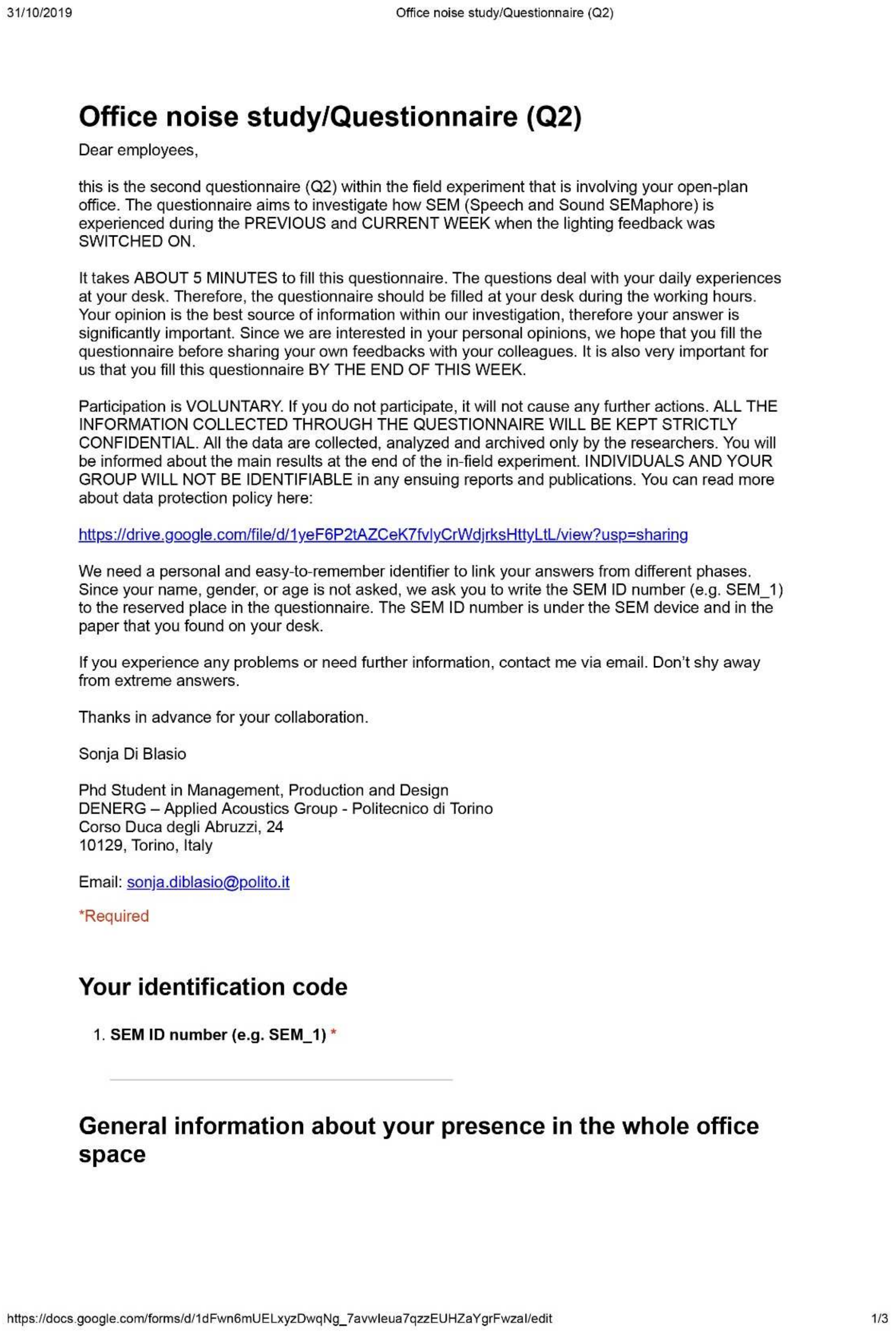
Appendix E

Open-plan office: Q2



Office noise study/Questionnaire (Q2)

Dear employees,

this is the second questionnaire (Q2) within the field experiment that is involving your open-plan office. The questionnaire aims to investigate how SEM (Speech and Sound SEMaphore) is experienced during the PREVIOUS and CURRENT WEEK when the lighting feedback was SWITCHED ON.

It takes ABOUT 5 MINUTES to fill this questionnaire. The questions deal with your daily experiences at your desk. Therefore, the questionnaire should be filled at your desk during the working hours. Your opinion is the best source of information within our investigation, therefore your answer is significantly important. Since we are interested in your personal opinions, we hope that you fill the questionnaire before sharing your own feedbacks with your colleagues. It is also very important for us that you fill this questionnaire BY THE END OF THIS WEEK.

Participation is VOLUNTARY. If you do not participate, it will not cause any further actions. ALL THE INFORMATION COLLECTED THROUGH THE QUESTIONNAIRE WILL BE KEPT STRICTLY CONFIDENTIAL. All the data are collected, analyzed and archived only by the researchers. You will be informed about the main results at the end of the in-field experiment. INDIVIDUALS AND YOUR GROUP WILL NOT BE IDENTIFIABLE in any ensuing reports and publications. You can read more about data protection policy here:

https://drive.google.com/file/d/1yeF6P2tAZCeK7fvlyCrWdjrksHttyLtL/view?usp=sharing

We need a personal and easy-to-remember identifier to link your answers from different phases. Since your name, gender, or age is not asked, we ask you to write the SEM ID number (e.g. SEM_1) to the reserved place in the questionnaire. The SEM ID number is under the SEM device and in the paper that you found on your desk.

If you experience any problems or need further information, contact me via email. Don't shy away from extreme answers.

Thanks in advance for your collaboration.

Sonja Di Blasio

Phd Student in Management, Production and Design
DENERG – Applied Acoustics Group - Politecnico di Torino
Corso Duca degli Abruzzi, 24
10129, Torino, Italy

Email: sonja.diblasio@polito.it

*Required

Your identification code

1. **SEM ID number (e.g. SEM_1)** *

General information about your presence in the whole office space

2. **When you are in the office, how many hours are you present usually at your desk?**
Mark only one oval.

○ 0 – 2 hours
○ 3 – 5 hours
○ 6 – 8 hours
○ More than 8 hours

3. **Do you have some fixed day when you are not in the office?**
Mark only one oval.

○ Yes
○ No

4. **If yes, which day/s?**

____

Your opinions about your experience with SEM during the previous and the current week when the lighting feedback was SWITCHED ON

5. **How much did you control or change your behaviour according to the lighting feedback of SEM during the previous and the current week? (Please, consider the moments of conversation or telephone calls)**
Mark only one oval.

○ Not at all
○ Slightly
○ Fairly
○ Highly
○ Extremely

6. **Do you think that SEM was in a good position on your desk to see the changing of the lighting feedback?**
Mark only one oval.

○ Yes
○ No

7. **Do you think that the colours of the SEM lighting feedback change correctly according to your speech and noise conditions present in the open-plan office?**
Mark only one oval.

○ Yes
○ No
○ Don’t know

8. **How often did you visit the web page to control data during the previous and the current week?**

Mark only one oval.

○ Never
○ Only rarely
○ Sometimes
○ Often
○ Very often

9. **How often did you check the results of the previous day through the paper on the wall?**

Mark only one oval.

○ Never
○ Few times
○ Almost every day
○ Every day

10. **Sometimes, did you perceive some malfunction of SEM (i.e. blocked lights, no lights) during the working day?**

Mark only one oval.

○ Yes
○ No
○ Don't know

11. **How much are you interested in having a device like SEM in your open-plan office?**

Mark only one oval.

○ Not at all interested
○ Slightly interested
○ Fairly interested
○ Very Interested
○ Extremely Interested
