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MANAGEMENT OF OCCUPATIONAL STRESS CAUSED BY CLASSROOM NOISE: CASE STUDY IN TWO FINNISH PRIMARY SCHOOLS

Master's thesis

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and all works, important standpoints and data by other authors
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has not been previously presented for grading.
The document length is 13590 words from the introduction to the end of conclusion.

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ABSTRACT

Teaching is perceived as stressful. The stress can be identified from the heart rate variability (HRV): high stress decreases the HRV. The classroom noise cannot be ignored when considering factors affecting teachers' performance and efficiency. The aim of the current study is to investigate, how the classroom noise influences teachers' HRV and their perceived performance. The HRV is recorded with chest belt monitor and the noise level is simultaneously assessed with hifi microphone. The stress and attitudes towards noise and its contributions to performance are clarified through the semi-structured interviews.

The noise is found to be a stressor causing frustration and physical symptoms such as headache and vocal problems. From the data gathered a connection between the noise and the self-assessed annoyance and an association to the measured HRV are identified. The classroom noise varies according to pupils' age, number of pupils, and the subject to be taught. The effects on performance and efficiency are seen due the fact that teacher must repeatedly use efforts to lower the noise level. No actual need for stress-related sick leave is observed, but in the case of prolonged exposure to noise, it is not considered impossible. However, it is essential to eliminate or reduce the noise sources.

One of the main objectives of the management is to ensure appropriate working environment for teachers, also focusing on the mitigation of the noise levels, either by technical or organizational solutions. The automated real-time noise and HRV measurements may provide additional support to decision-making. Teachers' occupational health and performance can be improved by implementing effective measures.

Keywords: Heart rate variability, Classroom noise, Teachers' Performance, Efficiency

INTRODUCTION

The educational system in Finland has transformed considerably during the recent years. Changes are noticeable in a physical and constructional environment but especially in the mental and pedagogical structure and the set of core values. Teaching is no more monologue, where the teacher is alone speaking while the pupils are listening quiet. Instead the teaching process is reciprocal communication between the educational personnel and the pupils, and between pupils themselves. The responsibility of the teacher is more likely to introduce the learning procedures and guide the pupils in their learning processes than solely to teach the required contents.

The Finnish educational curriculum for the primary schools emphasizes the meaning of the self-learning and the reinforcing the activity and the motivation of the pupils. It encourages to the peer-learning, group works and interactive discussing. (Opetushallitus 2020)

In educationally ideal situation, the sound environment in classroom is diverse. In the other hand, the realism of today is that the authority of the teachers is not more in the same level than decades ago, children are livelier than before and behavioral disorders are present increasingly. These combined with the fact that too big volumes of pupils, often for reason of economy, are placed in too small space, gain the sound environment inevitably. The noise level most likely remains within the norms, but despite the acoustics, the cumulative characteristic of the sound can rise the noise beyond the annoying levels and increase the anxiety.

Based on the studies, a large part of the teachers is suffering from the work-related stress at least occasionally. In some cases, the prolonged stress may lead to burnout. Because the well-being is an important part of the performance of the human, the impairment in physical or mental health is obviously affecting to the working ability as well. (Gray *et al*. 2017)

Besides the mental and social aspects, physical characters such as air quality, climate, lightning and acoustics are affecting the amenity of the educational environment. Although the hazardous limits are rarely overstepped, the quality of the indoor environment and especially the sound environment constitutes a significant factor influencing to the well-being and the performance of the teacher. Based on previous studies, the classroom noise has a direct effect on the subjectively analyzed stress levels of the teachers (Kristiansen *et al.* 2013). This evidence makes an expressive justification for the demands of the improvements in the physical educational environment.

Absolute productivity or effectiveness of the teacher is difficult to evaluate. Diverse factors are affecting to the ability of the teacher to teach as well as the ability of the pupils to learn. It is not possible to estimate rigorously the contributions of different things into outcomes. What is known for sure, is that the lowered performance of the teachers due presenteeism and the sickness absences is causing costs to different sectors of the society. (Rissanen, Kaseva 2014)

Managerial decisions are needed to improve the coping of the teachers. Hiring more teachers or other educational personnel for co-teaching lowers the number of pupils per supervising adult and helps the teachers to maintain their performance. Constructing larger school buildings for a declining population may not be sustainable solution, but expanding the use of existing classrooms, for example by splitting the school days into two shifts, will reduce the simultaneous workload of the teachers and other facilities. Paying attentions to dissatisfying factors such as annoying noise levels and investing to the acoustic solutions, it is possible to get the noise levels in balance. Improved quality of the education will repay the money invested.

Job satisfaction surveys assessed via questionnaires or interviews have a strong tradition in Finland. The surveys are often conducted regularly but generally not more than annually or less frequently. However, it is too common not to take action on the basis of the results. (Sosiaali- ja terveysministeriö 2005, 57)

To get reliable information in additions to surveys, there is a need for a valid method to impose the stress levels, preferably as real-time as possible, in order to introduce the preventive actions early enough to maintain the level of the teachers' well-being and educational performance. The heart rate variability (HRV) measurement is considered to be as an easy and affordable way to evaluate the stress levels continuously - changes in stress levels can be observed as changes in the HRV over a longer period of time (Kim *et al.* 2018).

The evaluation of the impacts of the noise imposed in normal educational situations on teachers' HRV is not covered extensively so far. This gives the justification to the focus of the current study.

The main research question is stated as follows: *What kind of managerial actions can be implemented in order to control the noise level in the classroom as one of the essential stress factors for teachers?* The sub-questions are: *How the noise level of the classroom and the heart rate variability (HRV) of the teacher can be measured in real-time, and how the noise level is affecting teachers' HRV and their perceived performance? What are the main safety improvements the management can implement in order to ensure controlled surrounding noise in the classroom?*

The current study focuses on clarifying the connections between the heart rate variability, the noise levels of the classrooms and the subjectively assessed stress levels of the teachers and teachers' attitudes towards noise in educational situations. The aim of the study is to investigate whether the changes in the measured noise levels in classrooms can be seen as the changes in the HRV of the teachers immediately or with very small delay. The study is conducted in two, small size Finnish primary schools as a case study, the other located in a small municipality in Finland and the other in the center of Tallinn, Estonia. Altogether six volunteer participants are involved in the study. The noise level of the classroom and the HRV of the teacher are measured simultaneously. The job satisfaction and the stress levels of the teachers and attitudes and observations towards noise and noise levels in classroom are assessed via semi-structured interviews after the measurement periods.

Chapter 1. includes the theoretical part, encompassing relevant topics such as stress, particularly occupational stress, the HRV and the noise, and their effects to well-being and performance. It also contains a review about previous studies related to the occupational stress of the teachers and the meaning of the noise exposure to the well-being and the efficiency as a general and in particular to the teachers. Chapter 2. describes the methodology, subjects and places and the procedures of the physical measurements and the semi-structured interview. It also gives a brief explanation of the measuring instruments and the interview framework. Chapter 3. consist of the results and the analysis including suggestions for managerial actions to mitigate the classroom noise, discussions, the limitations of the study and the further considerations. The Thesis ends on conclusions, where the whole Thesis is summarized briefly.

1. THEORETICAL BACKGROUND

The following chapters summarize the definitions and theories related to the parameters used in this study, such as the stress, the noise and the heart rate variability (HRV). The chapters reveal the methods and the results of the studies already conducted, including key conclusions concerning the effects of the stress and the noise on the HRV, the well-being and the performance in general, and in particular, to the teachers.

1.1. Stress and its effects on well-being and performance

In a common language, the stress has a negative sign. It is related to the expectations or demands that are more often unwelcome and seem to be impossible to implement, but need a response, or otherwise the situation will continue to be unpleasant. Generally expressed, the stress is the way of the human body to respond a demand.

Endocrinologist Hans Selye was the first one who used the word stress in the context of biomedicine. His definition for the concept of the stress was "nonspecific response of the body to any demand " (Fink 2017) followed later by more unambiguous version "a state manifested by a specific syndrome which consists of all the nonspecifically induced changes within the biological system" (Selye 1976). According EUs Framework agreement on work-related stress, the stress is described as "a state which is accompanied by physical, psychological or social complaints or dysfunctions and which results from individuals feeling unable to meet the requirements or expectations placed on them" (Monks *et al.* 2008).

The stress is not just a negative thing. Appropriate amount of stress can help to focus and improve functionalities. Based on the outcome, the stress can be divided into eustress, which appears to be good and helpful, and distress, which is considered as a bad and harmful stress influencing negatively to mind and body functions. (Szabo 2016)

Human function curve, or Stress response curve, determined by cardiologist Peter Nixon describes the level of the human performance as a function of the arousal stress (Nixon 1976). The performance level increases linearly with the arousal stress up to the turning point, after which the performance level starts to decrease. As the arousal stress continues to enlarge, the performance level will decline and eventually collapse, ending to the breakdown. The absolute value of the slope of the curve is smaller before the turning point than after, which means that the increase of the performance level is slower than the decrease with respect to arousal stress. The optimal zone, or comfort zone, for human performance is somewhat before the turning point. This is shown from Figure 1. The form of the curve is similar from one to another, but because of the individuality, the dimensions are varying. Some people withstand the stress more than others.

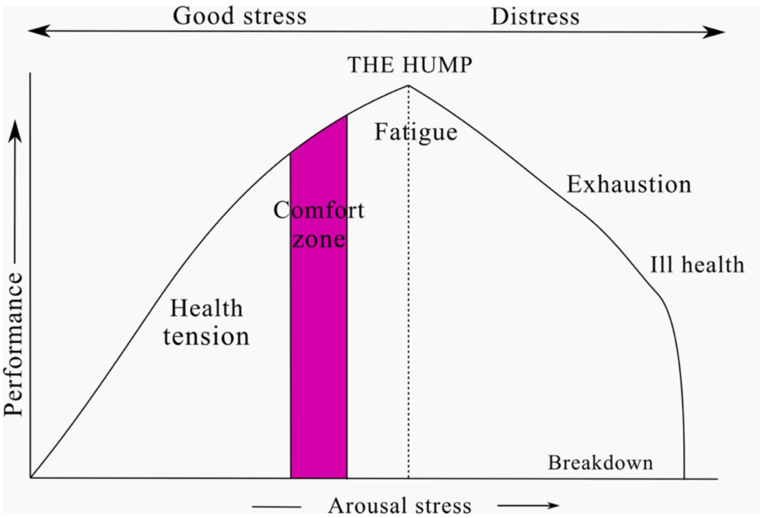

Figure 1. Performance under stress, The Human function curve introduced by P. Nixon
Source: (Nixon 1976)

Physiologically, the stress is based on the unbalanced situation of the sympathetic and the parasympathetic branches of the autonomous nervous system, and the constantly ongoing balancing activities which are influencing also to the heart and the heart rate variability (Massaro, Pecchia 2016). In most of the cases the acute stress is not harmful, but when the situation becomes chronic, the stress causes diverse symptoms such as fatigue, depression, insomnia, headache, elevated blood pressure and cardiovascular diseases and it decreases the immunity.

Enormous number of factors are influencing to the stress levels. Earlier in the history the cause of the stress was related directly to the worry about the survival. Nowadays the stressors are still associated to surviving but mainly indirect. Because humans are psycho-physical entities both emotional and physical loads have an impact to the human bodies and minds. The stress can arise foe example from health concerns, personal losses, financial insecurity, interpersonal problems and physical exertion. Stimulus from external environment such as noise, pollution, temperature and illumination can also contribute the stress. The term occupational stress refers to stress, which is coming from work-related issues. It can be caused for example by too high workload, imbalanced effort-reward ratio, lowered job satisfaction or impairments in physical working environment. The occupational stress is associated with the expectations the human imposes for himself or herself and the unreasonable demands of the members and other stakeholders of the work community. (Rashid, Zimring 2008; Mustafa *et al.* 2015) It is customary, that there is a mix of stressors from multiple sources accumulating and contributing to the well-being. Stress factors are highly subjective. The situation which causes severe stress to someone may not affect similarly to others, at least not to same extent. It is essential for well-being to identify the sources of the stress and try to mitigate them. Nevertheless, it is impossible to get rid of all the stressors completely, the important issue is to cope and manage the stress. Approaches to relieve the stress, such as deep breathing and mindfulness-based solutions, music, physical exercise and activities in the nature, especially in the forests have scientific evidence and can be used in the case of occupational stress also. (Labbé *et al.* 2007; Chan *et al.* 2019; Park *et al.* 2010)

1.2. Noise and its effects on well-being and performance

The noise is usually referred to as unwanted and unpleasant sound. The Merriam-Webster dictionary includes following definitions about the noise: "any sound that is undesired or interferes with one's hearing of something", "one that lacks agreeable musical quality or is noticeably unpleasant" or "loud, confused, or senseless shouting or outcry" (Merriam-Webster.com Dictionary 2020 *s.v.* noise).

The noise effects to the human body functions diverse ways. It does not only damage the auditory system; it also predisposes several dysfunctions and is a significant stressor (Heinonen-Guzejev *et al.* 2012). Westman and Walters (1981) point out that the noise is eroding the quality of the life in various ways. The noise disturbs the sleep, reduces the productivity and impairs the cognitive performance. The education and the development of the children is affected by noisy environments as well. Similarly, in their review Basner *et al.* (2014) emphasize the contribution of noise not only on auditory but also on non-auditory health effects such as annoyance, cognitive disability, sleep disturbance, and cardiovascular health. Goyal *et al.* (2010) examine in their research the effects of industrial noise on various noninvasive tests reflecting the functions of the autonomous nervous system. Long-term exposure to the high noise increases the release of several stress hormones, which throughout the functions of autonomous nervous system are influencing on the normal functioning of the cardiovascular, endocrinal, metabolic, gastrointestinal and neurological systems. The Dutch National Institute for Public Health and the Environment (2018) lists the sources and effects of the environmental noise to cardiovascular and metabolic system in its systematic evidence review report. World Health Organization has used these findings to develop the environmental noise guidelines for European Region.

The noise is considered to be one of the common causes of the problems in the workplaces, because its impacts on the performance are extensive. In additions to the intensity and duration of the noise, magnitude of the impact depends on the type of the noise and the task to be performed. While performing tasks that require precision and concentration, humans are more sensitive to noise interference than in less demanding tasks (Smith 1989; Szalma, Hancock 2011). Verbal noise is considered to be more annoying and have larger impact to performance than the same level background noise from machines, for example, and the tolerance for constant noise is better than for unexpected or inconsistent noise (Kjellberg *et al.* 1996). The stressfulness of the sound environment is a very subjective matter depending on diverse things, for example, is the noise wanted or undesirable, is the noise perceived pleasant or not, the intensity and the frequency of the sound and how long is the exposure time to the sound. Because of the subjectivity, specific noise such as certain type of music can have opposite impacts to different people. Alike the type of the noise can even determine whether the effect is positive or negative (Dalton, Behm 2007). The personality traits of the human can also contribute to the noise sensitiveness and the magnitude of the impact of the noise to the performance (Belojevic *et al.* 2003).

When discussing the noise levels of the rooms, buildings and public spaces, the noise means basically the level of the sound pressure. The harmful effects to human body depend on the intensity of the noise and the exposure time. EU defines the limits for the peak sound pressure and for the daily and weekly noise exposure levels as well gives instructors for management of environmental noise. The purpose of these limitations and guidelines is to reduce the risks and to protect human health and well-being. Even if no hazardous limits are exceeded, the effects to the human body and the mind can be extensive.

The noise environment in classrooms contains three major components. Continuous background noise from the heating, the ventilation and the air conditioning systems in addition to the lightning, and other electric devices such as computers forms one part. External noise consisting of the outdoor noise, which depends largely on the location of the school, and the noise coming from adjacent spaces, such as other classrooms, halls and corridors cover the rest of the background noise. Furthermore, there is the inside noise generated by the teachers and the pupils, such as the speech and reflected speech sounds and the noise from the movements of the humans as well as the furniture such as the chairs and the tables making the scratching sounds. It is markable, that higher ambient noise level indicates higher noise coming from the pupils. (National Research Council 2006)

1.3. Heart rate variability

The physiological theory of the heartbeat and the heart rate variability (HRV) is extensively researched topic. Understanding the HRV and phenomena behind it has expanded since 1850's together with the development of the modern physiology. Nowadays the HRV is widely used in health science research for the investigation of the physiological dysfunctions, diseases and the mental disorders. It is utilized parameter among the athletes and trainees wanting to monitor their exercise and recovery and favored among people interested in their overall well-being, including personal and occupational stress as well. The changes in the HRV are connected to the changes in physiological activity, especially in the autonomous nervous system. (Ernst 2017)

The heart of the human being is beating due to electrical activation, which starts from the sinus node of the heart. The activation proceeds throughout the heart with specific, repetitious order. When the electrical activity is recorded with electrodes, the data can be expressed as a graph, which is called as an electrocardiogram (ECG). In normal situation the waveform is recurring continuously similarly. (Niensted *et al.* 1999, 199) However, the healthy heart does not beat with exactly same intervals. In normal situations the heart is resilience and more responsive to fluctuations than abnormal situations. One interesting characteristic of the ECG is the RR-interval, which means the time interval between the adjacent R-peaks. Especially when investigating the HRV, the RR-interval plays a large role. In Figure 2. is a graph of the ECG-signal, from where the repetitive waveform and RR-interval can be detected. (Cornforth *et al.* 2014)

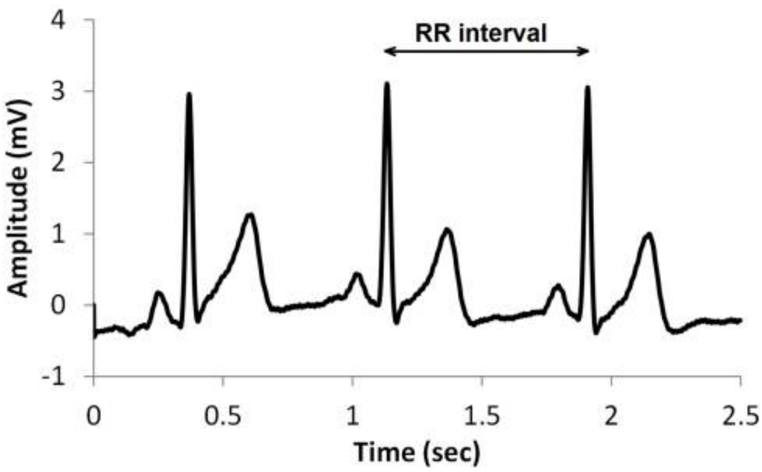

Figure 2. The ECG-signal and RR-interval
Source: (cc by) (Cornforth *et al.* 2014)

Numerous physiological factors are affecting the HRV, such as age, gender (Voss *et al.* 2015), circadian rhythm and genetics. Several physical and mental diseases have an impact to the HRV. Life-style factors, like physical condition and activity, body mass index, alcohol abuse, smoking and meditation can influence the HRV as well. In addition, certain external factors, such as noise, heat, electromagnetic fields, vibration via tools and equipment, night shift work and medication effect the HRV. (Sammito, Böckelmann, 2016a, Fatisson *et al.* 2016) The classification of the general factors contributing to the HRV is summarized in the Table 1.

Table 1. Factors affecting to the HRV

Non-modifiable factors	Mental factors	Diseases	Lifestyle factors	External sources
• age • gender • ethnicity • genetics • circadian rhythm	• stress • depression • emotions	• sepsis • heart diseases • lung diseases • renal diseases • metabolic diseases • psychiatric diseases	• physical condition • activity • body mass index • smoking • alcohol abuse • meditation	• noise • heat • vibration • electromagnetic fields • night shift work • medication

Source: (Sammito, Böckelmann, 2016a, Fatisson *et al.* 2016)

The general reference values give rough estimates of the appropriate HRV levels. By comparing the results of the individual to the reference values it is possible to get a hint about the normality of the person's HRV. However, because of the numerous contributing factors, it is not reasonable to compare the HRV between separate individuals but merely to focus on analyzing the variation of the HRV of the one and the same individual over time. Short- and long-term fluctuations are telling the changes in the health condition of the investigated people.

The collected data via wearable heart rate sensors consists of the times of the adjacent RR-intervals. To make the further analysis there has evolved the need to compute statistical quantities, such as indexes or different coefficients, which are characterizing the HRV. Computing can be done, for example, using time- and frequency-domain methods as well as non-linear methods. To make the practice more consistent The Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology (1996) have elaborated the guidelines for the appropriate standard measurements, physiological interpretation and clinical use of the HRV. Some of the simplest time-domain coefficients are the mean of the RR-intervals, the mean heart rate and the difference between the longest and shortest RR-interval. It is also possible to calculate more complex statistical time-domain coefficients such as standard deviation of the RR-intervals (STDEVRR) and the square root of the mean squared difference between adjacent RR-intervals (RMSSD) from the longer recordings. In the frequency-domain it is conceivable to determine the estimate of the power spectrum density (PSD) for the RR-intervals. The PSD indicates how the power is distributed as a function of the frequency. The prevailing technic to evaluate the spectrum in HRV analysis is Fast Fourier transformation (FFT) based methods. It is generalized to use the three main frequency bands: the very low frequency 0.003 - 0.04 Hz (VLF), low frequency 0.04 - 0.15 Hz (LF) and high frequency > 0.15 Hz (HF) components for the analysis. With advanced algorithms, it is doable to calculate parameters using non-linear methods. In the extremely complex human body, the non-linear mechanisms are affecting to the heart rate thus giving the justification to use these in HRV analysis. (Ibid.)

1.3.1. Stress response to the heart rate variability

The connections between the heart rate variability (HRV) and the stress levels are extensively investigated topic. Studies have shown a unified line in the behavior of the several HRV parameters under the stressful situations. Based on the review of Castaldo *et al.* (2015) the increase in heart rate and the increment in the LF and the decrement in the HF component of the HRV are observed during the acute stress. The review also points out parameters such as STDEVRR and

RMSSD having negative correlation to the stress levels. Delaney and Brodie (2000) shows in their study that exposure to the physiological stress decreases the standard deviation of the RR-intervals. It also reduces the HF component and increases the LF component of the HRV thus raising the LF to HF ratio. The HRV is one of the most used physical measures to associate the work-related stress. Several researches have shown the significant correlation between the occupational stress and the parameters evaluated from the HRV. In their review Järvelin-Pasanen *et al.* (2018) found a connection between the heightened occupational stress and the lowered overall HRV, decreased RMSSD and reduced HF component. Based on the study of Orsila *et al.* (2008) there is a high negative correlation between the self-assessed mental stress and the RMSSD as increasing RMSSD indicating lower stress levels. The study also reveals that the elevated LF component of the HRV is associated with high work stress. Stress decreases the HF component as well and increases the ratio between the LF and HF components. Uusitalo *et al.* (2011) found connection between the various HRV measures and the self-reported chronic stress in their research. Especially, the higher work effort indicated a lower daytime HRV. The work effort is also related to self-assessed daily work time emotions. Widely used HRV related parameters mentioned above and their responses to stress are collected to Table 2.

Table 2. HRV parameters and the effect of the stress

Parameter	HR	HRV	STDEVRR	RMSSD	LF	HF	LF/HF
Response	↑	↓	↓	↓	↑	↓	↑

Source: Made by author

As a summary, the stress-induced changes are as follows: heart rate is raising whilst the overall level of the heart rate variability is lowering. The time-domain parameters STDEVRR and RMSSD are decreased under the stress, whereas in the frequency domain the low component LF is increased and the high component HF is decreased, and the ratio LF/HF is increased.

1.3.2. Noise response to the heart rate variability

Noise response to the HRV is widely studied. The noise is considered as a significant stressor for the human body, and the physiological effects of the noise can be detected by the HRV. Based on their study, Kraus *et al.* (2013) state that the noise exposure can be observed as the immediate changes in the HRV monitored during daily routine activities, for example as concurrent reductions in the time-domain parameters of the HRV. Similarly, El Aarbaoui *et al.* (2020) find connections between the changes in the HRV and the noise exposure perceived in daily locations.

The increase in sound level is interpreted as immediate effects on the HRV and delayed decreases in the overall HRV. The location where the exposure occurred, is relevant to the level of change. Sim *et al.* (2015) analyze the effects of the noise types rather than the noise intensity on the HRV. After the exposures with background, traffic, speech, and mix of traffic and speech noise, slightly differences are observed in the HRV based on the noise type. Nardelli *et al.* (2015) apply pleasant and unpleasant sound with four separate intensities to make the stimulus. In additions to the fact that the type and the intensity of the noise have an effect on the HRV response, they find an evidence that different emotional states induced by the noise can be recognized from the HRV.

Chen *et al.* (2014) investigate in their study the effects of low frequency noise exposure with distinct intensities on the HRV parameters. They conclude that the noise exposure has significant effect to the temporal correlations of the HRV but did not influence extensively to variability of RR-intervals. Idrobo-Ávila *et al.* (2018) clarify in their review, how the different types of the sounds are influencing cardiovascular system. Among investigated studies common elements are found; the blood pressure and heart rate tend to increase with unwanted noise stimuli, the HRV parameters HF and LF/HF change with both the pleasant sound and unpleasant noise stimuli and LF changes with the exposure to noise.

1.4. Teachers' occupational stress and the noise of the educational environment

There is an extensive list of scientific papers related to the stress of the teachers. Also the impact of the noise on teachers' well-being and performance is widely studied. However, only a limited amount of studies where the level of the stress or the impact of the noise is measured by physiological measurements exists, and there is almost an absent of the studies, which are focusing on investigating the impacts of the noise on teachers' HRV in real-time in classroom situations.

Most of the studies related to the occupational stress of the teachers are conducted using questionnaires as a data collection method. Majority of the research teams are using already existing, well-known test patterns and test instruments such as Maslach Burnout Inventor, Occupational Stress Inventory or its revised version, Teacher Job Satisfaction Questionnaire and Teachers Stress Inventory to assess the working and especially teaching related stressors. (Maslach *et al.* 1986; Osipow 1998; Lester 1987; Fimian 1984) In some researches several different test instruments are used and compared the relevancy of them. (Mahan *et al.* 2010) Few of the studies are focusing to develop new test patterns to fit better for the specific context, for example to educational occupations, or different nations. (Kristensen *et al.* 2005; Tsigilis, Koustelios 2019; Taddei *et al.* 2017; Naono-Nagatomo *et al.* 2019) However, 'new ones' are often using already existing test instruments as a base. Some of the studies investigate, how the demographic parameters such as gender, age, education level, or years of experience contributes to the stress levels of the teachers (Gold 1985; Ritvanen *et al.* 2006; Aftab, Khatoon 2012; Boström *et al.* 2019), how the size of the school, how the academic level in which the teacher is teaching, or how the location of the school is affecting to the job satisfactory of the teachers (Byrne 1993; Abel, Sewell 1999). Many of the researches investigate the situation in a specific country (Nagai *et al.* 2007; Leung *et al.* 2009) or compare the situations between different countries (Pithers, Soden 1998; García-Arroyo *et al.* 2019). In a few of the cases the focus is more in the work-related factors such as the work overload, the working conditions, the working climate or organizational decisions and how these contribute to the teacher's well-being, job satisfaction or work commitment (Skaalvik, Skaalvik 2009; Van Droogenbroeck *et al.* 2014).

The stress response of the teachers can be interpreted from the interfered secretion of the saliva-cortisol (Nislin *et al.* 2016; Parent-Lamarche, Marchand 2018). As with the occupational stress general, the heart rate and the heart rate variability are commonly used physiological parameters when evaluating the stress levels of the teachers (Wettstein *et al.* 2020). In the majority of the cases the results based on these ambulatory assessment methods are compared to the data collected via surveys.

Seetha *et al.* (2008) find that noise level of the classroom has impact on the health and the mood of the teacher. The study also reveals that the noise affects to teaching process negatively. Kristiansen *et al.* (2013) address more specifically the self-assessed effects of the noise on teachers' health and performance, such as job dissatisfaction, lack of energy and motivation and fatigue after the working day. Eysel-Gosepath *et al.* (2012) find by questionnaires that the two-thirds of the teachers are annoyed by the noise in their working environment. Besides the mental aspects, such as the job dissatisfaction and the lack of motivation, it is common that teachers have physical disorders, such as headache and voice problems due to speaking too loud over high noise. Occasionally the sick leave is needed for example for the voice recovery. (Skarlatos, Manatakis 2003; Kristiansen *et al.* 2014; Hadzi-Nikolov *et al.* 2013).

2. METHODOLOGY

The current study evaluates the impacts of the noise on teachers' occupational stress, well-being and performance. It is shown that the noise can be seen as a stressor affecting diverse ways in mental and physical well-being (Heinonen-Guzejev *et al.* 2012). Based on that, it is assumed that it is possible to assess the impacts of the noise similar ways than the effects of the other general stressors.

The aim is to get the information from the real educational situation. Protocols conducted in laboratory or other simulated conditions where the investigated person is exposed to artificial noise, is not suitable for this context. Questionnaires are widely used to assess the effect of different stressors on well-being and performance, and it is possible to use those in a case of noise impacts as well. The difficulty of this kind of subjective method is that self-evaluation is generally troublesome. Another problem arises from the challenges to find the exact questions or phrases, which words the characterized phenomenon of interest correctly. (Bianchi *et al.* 2017)

The level of the stress can also be associated to saliva cortisol secretion. The stressors are interfering the secretion of the cortisol. Increased level of cortisol positively correlates the increased level of stress. Saliva test samples are easy to collect, and the method is affordable and accurate, but the analysis is needed to be done in laboratory (Takai *et al.* 2004; Bigert *et al.* 2005). There is also an obvious connection between the stress and the blood pressure (Matthews *et al.* 1987; Vrijkotte *et al.* 2000). Blood pressure measurement is an easy, inexpensive and non-invasive way to monitor stress level. However, it requires peaceful settlement of the measurement situation, and it is not convenient as a continuous measurement.

The heart rate variability (HRV) is considered as a reliable indicator of the stress. There are relations between the physiological functions of the human body and the HRV as well as between the stress and the HRV (Kim *et al.* 2018). The HRV is seen to be a proper method to assess the impacts of the noise for the current study, because it is an easy, inexpensive and non-invasive method. With modern technology it is available for continuous, real-time measurements and it is fluently exportable to the school environment. In addition to the HRV measurements, it is decided to conduct semi-structured interviews to the participants to determine also the effects of the noise to the annoyance and the performance of the teachers subjectively.

2.1. Background of the *in-situ* places

The study is conducted as a case study in two Finnish elementary schools: Tallinnan suomalainen koulu (Finnish school of Tallinn), TASK, and Aseman koulu, located in Tallinn, Estonia and in Urjala, southwestern Finland, respectively. The schools share lot of similarities even though TASK is a private school and Aseman koulu is a public school. Both schools follow the Finnish educational curriculum, the teaching language is Finnish, and the majority of the pupils and the teachers are Finnish having a Finnish citizenship.

The city of Tallinn has about hundred times more habitants than the municipality of Urjala. The school building of TASK is close to the center of Tallinn, in the neighborhood of Kadriorg whereas Aseman koulu is located six kilometers from the center of Urjala municipality. However, both schools are considered as small size village schools with circa hundred pupils and ten to fifteen teachers. The schools are situated away from the traffic noise meaning that the outdoor environments of the schools are mostly quiet, with exception of the breaks between the lessons, when pupils are in the school yard and often make loud noise.

Both schools are operating in old buildings. Aseman koulu is originally constructed for school purposes in 1960s and has been expanded and renovated over the years. The current building of TASK is originally built as a dormitory in 1950s. The exterior has been preserved but the interior has thoroughly rebuilt in 1990's. The floor areas are approximately the same, facilities are functional, and the buildings are discovered healthy without any identified indoor air problems. In addition, the organizational structure and the working atmosphere are perceived generally good in both educational units.

Due to the several similarities and general stress-free atmosphere of the educational units, it has been considered that these two schools and their teachers are suitable for the research investigating the assumed stress effects of the noise on teachers' HRV and performance. A flat and uniform background is advantageous because otherwise it would be more difficult to investigate and discern whether the response in the HRV is via noise or via other teaching and work-related stressors that occur in the work environment during the measurement periods.

2.2. Participants of the study

Altogether six teachers participate the study: three teachers in TASK and three teachers in Aseman koulu. The demographic parameters of the participating teachers are collected to Table 3.

Table 3. The demographic parameters of the participants

	Place Task/Asema	Gender [1]	Age years	Experience ~ years	Years in Current Place	Educational level [2]	Main position
E1	TASK	M	42	10	3	P	Subject
E2	TASK	F	43	4	2	E	Class
E3	TASK	F	58	5	5	E	Class
F4	Asema	F	43	18	15	E	Class
F5	Asema	F	41	16	8	E	Special needs
F6	Asema	M	51	27	26	E	Class

Source: The semi-structured interviews made by author
Notes: [1] F - female, M - male; [2] E - grades 1. - 6., P - grades 7. - 9.

There are two female teachers and one male teacher from both places. Most of the participant are bit over 40 years but one is clearly closer to 60 years. Four of the teachers have more than ten years of educational experience and two around five years of experience. Four are class teachers, one subject teacher and one of the teachers is a resource and special need teacher, and all teachers except one are teaching mainly grades one to six, the one is teaching grades seven to nine.

2.3. Measurement and interview procedures

The physical measurements consist of the simultaneous quantitative measurements of the noise level of the classrooms and the heart rate variability (HRV) of the teachers. Two separate measurement sets described in more detail in Chapter 2.4. are available for physical measurements, meaning that it is possible to take weekly measurement for two teachers at the same time. Although the aim is to monitor the noise levels and the HRVs during the adjacent four weeks, the study has to be restricted and the original plan needs to be modified, for the reason of the self-isolations, guarantees and finally, the closing of the schools both in Estonia and in Finland as a precaution to pandemic COVID19. Ultimately during the period of two weeks the heart rate of six participants are monitored at several working days, approximately one to six hours per day depending on the timetable of the teacher being measured. Simultaneously the noise levels of the classroom are recorded.

The qualitative semi-structured interviews are conducted to determine the work-related stressors and the stress levels of the participating teachers, the subjective annoying effect of the noise and the impact of noise on teachers' performance and efficiency. A broad mapping of the stressors is essential because it is important to consider what are the possible contribution of the noise as well as other stressors to the HRV, when drawing conclusions about the impact of the classroom noise on the HRV of the teacher. The interviews are done to five participants after the related quantitative measurements are finished, whilst the interview of one participant is omitted for personal reasons. Two of the interviews are done in face-to-face meetings, but due to circumstances, three of the interviews are done by phone instead. All the interviews are conducted in Finnish by the author of this Thesis and are recorded and transcribed. The longest interview takes approximately one hour, the shortest bit over 20 minutes and the rest are around 40 minutes.

In addition to the procedures mentioned above, the timetable of each teacher is collected to reveal, what kind of subjects are taught in which time. The teachers are asked to keep an hourly based diary, in which they make short notes of his or her feelings and the opinions of the noise level of the class during the measurement period, but the completion rate of this was only one of six.

2.4. Measuring instruments

The technical aspects how to reliably measure the heart rate (HR) and the heart rate variability (HRV) are well known. The principal ways to assess the HRV are the electrocardiogram (ECG) recorder and personal HR monitors. The wearable heart rate sensors such as chest belts are seen as a comfortable, non-invasive and affordable way to measure the HRV. Additionally, the wrist bands with optical sensors and developing technology provide adequate validity and good applicability to detect the R-peaks and RR-intervals. The level of needed confidence depends on the context of the use. Wrist bands are sufficient for individuals monitoring their well-being, chest bands are recommended to use more accurate research purposes whereas the ECG recorder is the optimal choice in diagnostic related researches and clinical use. (Sammito, Böckelmann 2016b)

In Aseman koulu the heart rate monitoring of the participants is done with Polar H10 heart rate monitor (Polar 2020). In TASK, SunDing SD-520 Heart Rate Monitor (Sunding 2020) is used to record the heart rate. Both monitors have bluetooth connection and are compatible with many commercially available HRV applications for smartphones. Belts are considered to be reliable enough for the HRV measurements and the R-peak and RR-interval detection in this kind of context, where the purpose is to investigate and promote the well-being, even those are not adequate for clinical diagnostic or medical use. (Sandercock *et al.* 2004; Nunan *et al.*2009; Porto, Junqueira Jr 2009; Guzik *et al.* 2018)

In Aseman koulu, the HRV data recorded with Polar H10 sensor including the time stamp is automatically sent via bluetooth to Raspberry Pi (Raspberry Pi 2020) minicomputer and stored to SD-memory card, wherefrom the data is available for further analysis and review. It is also possible to send the data directly to the cloud, from where the data is reachable regardless the physical location of the measurement system. Because of the short measuring period of few weeks and before knowing the upcoming travel ban situation, the SD-card as a more secure and conventional way was chosen. In TASK, the smartphone application EliteHRV (EliteHRV 2020) is used to collect and restore the HRV data and the time stamp got via bluetooth from the chest belt. Based on the former research, EliteHRV is concerned to be competent application for this kind of purposes (Perrotta *et al.* 2017). From EliteHRV the data can be downloaded fluently for further analysis as well.

The noise of the classroom is measured using a standard hifi microphone connected to Raspberry Pi minicomputer in both places. The microphone is located in the front of the class at the desk to a height of about 100 cm and is directed towards the pupils. The microphone provides an estimate of the sound pressure of the classroom from the location where the teacher is most likely to be most of the time. The evaluated sound pressure over ten second time intervals is transformed immediately into frequency domain to guarantee the anonymity of all the people in the classroom during the measurements. The data with a timestamp is backed up to SD-card. However, likewise the HRV, the noise data can be uploaded directly to the cloud for further analysis. The noise measurement system can be calibrated to standard decibel values. The noise data assessed in the current study is recorded using two similar systems and thus the data is comparable within the study.

The semi-structured interview frame is created and followed when interviewed the participants of the study. The questions are outlined to multiple sections concerning different aspects of the possible stressors in teaching and the educational environment. Also, parameters related to indoor environment quality are added to the interview to find out the importance of the physical properties of the school buildings and the classrooms and their influence on teachers' performance. Complementary questions covering the noise and the consequent annoyance and the mental and physical effects to teachers' well-being and occupational health are also included to the interview.

The Maslach Burnout Inventory (MBI) is used as a guideline when the questions concerning the workload and the mental stressors are deliberated and the structure of the interview is designed. Whereas the items to be answered at the MBI are statements with specific scale (Maslach *et al.* 1986), most of the questions in the interview are formulated and presented as an open-ended form. An English version of the semi-structured interview framework is given in Appendix 1. The interview plan is used to direct the conversation with the interviewer and the interviewee, but the purpose is not to follow it as word for word or even as question by question hence allowing an interactive way to guide the discussion and to bring new aspects beyond the framework.

3. RESULTS AND ANALYSIS

The qualitative data gathered via interviews is examined to find the major factors, which are burdening teachers in their work and working environment. Particularly the opinions on noise, its nuisances and relevance for the work performance and the efficiency are in the focus of the attention. Also, the similarities and the disparities between the schools are sought more deeply to draw the conclusions in what kind of conditions the results may be valid. The information obtained from the interviews and the conclusions of the author of this Thesis are summarized in the Chapter 3.1.

There exist distinct commercially available software for the scientific analysis of the HRV data for personal as well as more professional purposes. Most of the heart rate monitor manufacturers have integrated their own HRV analysis software to chest belts and smart watches providing an easy way to analyze and interpret the data. Also, there are smart phone applications for the HRV analysis. A suitable tool for the analysis needs to be chosen depending on the purpose and the amount of data to be analyzed.

The heart rate monitors used to record the HRV in the current study send the data and store the information as a form of the time difference between the adjacent heart beats in millisecond units. From the files the data can be read directly to the spreadsheets program, designed analysis software or to some mathematical programming language such as MATLAB. However, the sophisticated open source programming language Python powered with Pandas, the data analysis and manipulation tool, is used to analyze the data (McKinney 2010; Python Software Foundation 2020). Programming is made in co-operation with the colleague of the author of the Thesis. Likewise, the data from noise measurements are preprocessed and analyzed with Python. The analysis and the results based on the noise data and the HRV are gathered in Chapter 3.2. The codes used in the preprocessing and analysis are found from the Appendices 2A, 2B, and 2C.

Besides the Python, the commercial MATLAB based analysis software Kubios is used (Kubios 2020) as a reference to verify exactness of the Python code. Kubios calculates the main coefficients, makes analysis and gives a compact report of results with a short interpretation. It is good and very versatile software, and it produces a lot of analytical data. Nonetheless, some of them are irrelevant for this study. The disadvantage of Kubios analysis is the surprisingly long opening and downloading time of the recorded HRV datafiles, perhaps due the capacity of the laptop in use. In addition, the temporal allocation of the noise data and the HRV data is not possible in Kubios. However, the Python programming language allows to do everything needed rather easily.

3.1. Interviews

The analysis of the interviews is divided into subsections as follows: Mental, social and emotional environment, Occupational issues, Physical environment and facilities and Noise level and its effects. Each section contains analytical and empirical considerations connected to theories.

3.1.1. Mental, social and emotional environment

According to the interviews, the mental working environment is perceived as good if not even excellent in both educational units. The teachers stated as follows: *'At the moment the atmosphere is good, relaxed, you dare to be yourself and you do not have to present anything else.' (E3) 'Positive atmosphere, human-centric.'(F4) 'There is a good atmosphere.' (E1)* A small number of teachers makes it possible to form close relationships between the teachers and other personnel of the schools. It is allowed to discuss openly and truthfully, and teachers can express their disagreements freely. *'It is possible to give feedback and express own opinions…dare to disagree and oppose, and still things are going well. Small size is a huge advantage.'(F5)* The threshold for asking for and receiving peer support as well as the support of the supervisor is low. *'I think you can get enough support.'(E3) 'Yes, whenever you ask, you get it.' (E1) 'You will receive support, both professional and personal level.' (F5)* Even there do not exist unnecessarily rigid hierarchical structures, the principals of the schools attend to their leadership and supervising role properly. *'A close supervisor relationship works great.' (F4) 'Supervisor relationship is working well, however, she is a leader when a leader is needed.' (F5) 'Yes, everything has gone well.' (E1) 'Supervisor relationship, it works, I think it works really well.' (E3)*

A small number of pupils allows to know everyone in the school personally. The same concerns to the parents or the guardians of the pupils, which makes the communication immediate and uncomplicated in majority of the cases. Pressure coming from the relationship between teachers and parents or from the expectations of the parents is not noticeable at all. One experienced teacher summed it up as follows: *'Either the parents are confident, that things are going well, or they have lost hope that nothing would change despite the (parents') expectations, and they are expecting nothing anymore.' (F6)* There is neither significant pressure nor expectations from the colleagues or from the management level. It seems that some teachers set too high expectations for themselves. *'Maybe I have set the hurdle bit too high for myself.' (F5)* According to one teacher, time to time it is good to remind yourself that it is enough as long as you do your best. *'However, there are pupils, who do not achieve top results no matter what is done.' (F6)*

All the teachers agreed that they are feeling good in the mornings and are willing to go to workplace. *'It feels good to go to work, although sometimes morning routines can be just as hassle with my own kids.' (F5) 'I like to come to school.' (E3)* After the workday, feelings remain positive though few of the interviewees felt sometimes tired. *'I am happy, but tired.'(F4)*

The importance of the interpersonal relationships and the supervisor support is recognized when looking for factors that affect teachers' job satisfaction and ability to work (Skaalvik, Skaalvik 2009). An open atmosphere is conveyed through the interviews. Teachers in both schools are satisfied with their relationship with each other and with other stakeholders. The supervisor relationship is highly appreciated. Workdays start and end mainly with positive feelings and teachers seem to be happy most of the time at their workplace.

3.1.2. Occupational issues

The teaching is perceived as meaningful and rewarding. Feedback, especially from the smaller pupils, is spontaneous and it is mostly positive. *'Teaching, as an occupation, is versatile.' (F4) 'When you realize that they learn, and you have been involved.' (F5)* Compared to the ideals of the studying times, the actual work, sometimes, focuses more on the educational aspects than on the teaching itself. *'I think the job is more about educating and guiding in the right direction than teaching. But I feel it important, that makes those children grow into sensible people.' (F5)*

The work is intense, often with challenges, but those are observed mainly as positive and rarely seen as insurmountable. The workload is large, but manageable. *'There are challenges. But if it goes too smooth, then you have to develop something for yourself.' (F4) 'Teaching is quite versatile. It is not monotonous at all. Various systems and everything. It is pretty interesting.' (E1)*

Every now and then, the rush is experienced frustrating, and, for example, bureaucratic things can take considerably time. In addition to the actual teaching day, time is spent on other teaching-related issues, such as preparing lessons, checking the exams, communicating electronically or face-to-face with pupils' parents, and various other topics. Most of the teachers agrees that they try to do all the work at workplace and do not take ‘work’ to home to better maintain the line between work and leisure time. According to one teacher, the strict decision not to work at home helped to relieve the feelings of the stress. *‘At one point of my teaching career I made decision, that the work would be done at workplace and not taken to home, even though it would take longer days. It did alleviate the work stress.’ (F6)* Most of the interviewees appreciated long vacation periods highly and those are considered as deserved as well as necessary benefits of the work. *‘Yeah, long vacation, it will compensate all.’ (E1)* All the respondents agreed, that within the curriculum, teachers have the opportunity to carry out their teaching in their own individual way, giving the room to more creative or more traditional approaches depending on the personal preferences. One respondent emphasized in particular the essentiality of flexible and autonomous work. *‘I can influence a lot how I do my job and it is really essential for me.’ (F5) ‘Reasonable free. The time schedule makes the limitations. (E1)’ ‘The pedagogical freedom is the privilege of Finnish educational system.’ (F6)*

Low retention rate is the characteristic feature of TASK. It is due to the bureaucratical reasons that many of the Finnish teachers of TASK are on secondment for two to five years, only, and not because of the teachers want to change the workplace. The teachers’ turnover has made the atmosphere very flexible and adaptable. Whereas in Aseman koulu, most teachers are long-term employees and the personnel seem to be more polished together. One of the interviewees stated: *‘It can be difficult for newcomers to adapt to the working community in Aseman koulu.’ (T5)*

The workload of the teaching and the non-teaching activities, such as paperwork, and time-pressure are concerned factors affecting teachers’ exhaustion. The autonomy of the work increases the satisfaction and relieves both the feeling of the rush and the exhaustion. (Van Droogenbroeck *et al.* 2014) The workload and the autonomy seem to be in appropriate levels in both units ensuring teachers’ job satisfaction.

3.1.3. Physical environment and facilities

Both schools are operating in old buildings, which have been renovated over the years according to the needs as much as it has been possible within the budgets. There are separate rooms and special spaces for each grade level and for subjects such as handcraft, music and sports. *'Originally the building is not constructed for school purposes, but our classroom is big enough for us.' (E3) 'The building is in good condition. Maybe the sport hall could be bigger.'(F5) 'Classrooms are renovated, and anyway, we have bigger classrooms than new schools' (F4)* In either school there are no modern open-space learning environments, but it is seen more as a positive thing than a disadvantage. Due to the lack of the general space or extra rooms, the halls and the corridors are used as a teaching environment, if it is necessary to split the groups into even smaller entities. *'I think in horror about those open learning environments, after all, there is quite a fuss when many classes work in an open space.' (F4)* Very important issue is, that both schools are found to be healthy working environments based on the air quality measurements. One interviewee capsulizes this to sentence: *'Modern facilities are of no use, if the environment exposes to the health hazards.' (F6)* In the opinion of all teachers, physical aspects are altogether in good estate. The classrooms are in moderate condition; convenient, adjustable but not too large. *'There could be more space on my classroom.' (E1)* The air conditioning, ventilation and acoustics are the major concerns, when discussing the indoor environment quality in both places. *'Well, air conditioning, probably, in some classrooms, works poorly, especially when there is warmer weather.' (F5) 'Sometimes more ventilation would be needed.' (F4) 'The acoustics in the classes are probably ok, but there is only little sound insulation between the rooms.' (E1)*

Teaching materials and equipment are up to date. There are computers or laptops, and video projector in every classroom and enough software applications for normal teaching needs. Besides in Aseman koulu there are three big brand-new smart boards. In TASK the small number of present-day laptops for pupils is said to cause sometimes inconvenience when using digital materials. Another annoying thing is the occasionally inadequate network. *'We have modern equipment right now.' (F4)*

In TASK the number of the pupils in the same grade varies being about ten pupils, the minimum and maximum being four and fourteen, respectively. In some subjects two consecutive levels are combined as a one group for a lesson. Even then, the maximum number never rises above twenty. In Aseman koulu the appropriate human resources have made it possible to maintain the sizes of the groups between 13 and 19 pupils. Most of the teachers estimated that the overall optimum capacity relative to the size of the existing classrooms would be around 15 pupils. Generally, less than 20 pupils per class are considered appropriate. *'Nice little groups' (E1) 'There should not be more that 20 pupils in one class.' (E3) '20 is still ok, but 24 too much, even you had a school* *assistant with you.' (F4) 'I have experience from group sizes starting from under 10 to more than 35, I would say that neither too small nor too big groups are convenient for the teacher or the pupils.' (F6)*

It is known that the components of the indoor environment, such as air quality, climate, lightning and acoustic, have an impact on occupational stress and well-being (Al Horr *et al.* 2017). The quality of the physical environment appears to be in appropriate condition in both schools. Although space is limited in classrooms, moderately small group sizes especially in TASK make space adequate in the sense of the indoor air quality and most of the cases to the noise environment. Good facilities guarantee comfortable working despite the occasional distractions.

3.1.4. Noise level and its effects

Based on the qualitative information gathered via the interviews, the noise levels are rising every now and then but however being adequate most of the time. *'It can't be too quiet, there must be such a suitable noise level.' (E1) 'My class is, how would I say, lively.' (E3)* The noise level is greatly depending at least on the age of the pupils, the subjects to be taught and the available room space. *'It depends a lot about the pupils, in the sixth grade it would not matter, but for the first grade, it would be disaster to have more pupils.' (F5)*

From teachers' assessments, the assumption that the noise level is heightening during the ongoing school day and during the ongoing school week, can be observed. The noise level differs between the groups, which is understandable when taking into account the variables such as the group sizes, the age of the pupils and the nature of the subject to be taught. *'The morning hours are the most peaceful.' (F5) 'The rest of the week is more restless.' (F4) 'Of course, it varies. Sometimes pupils are quiet and listening. Some works are done louder.' (E1) 'Monday is the day when everyone is talking enthusiastic about the weekend greetings, but in positive way. Towards the end of the week, there is the restless noise coming.' (E3)* One of the teachers stated: *'Morning hours seem to be more quiet than afternoons. This issue will be taken into account in the planning of the schedule, and subjects, which require more concentration, such as math and languages, are placed before noon, if only the resources and facilities allow.' (F6)* A few teachers also thought that based on the subjective evaluation of the noise level, it is difficult to assure, is the noise level really increasing towards afternoon lessons and towards the end of the working week or is the teacher' tolerance to the same level noise decreasing during the week. *'If I am tired, I think I am more sensitive to noise.' (F5)* On the other hand, the perception of the noise level and the annoying effects of the respondents are changing depending on the type of the noise, even if the physical intensity is the same. *'It is about your own feeling, what kind of sound or noise is annoying and when.' (E3)*

Associations between the observed noise levels and the stressfulness, or rather the annoyingness, of the teachers can be perceived - increased noise level indicating more annoyed teachers - but not for all. Most of the respondents expressed that they have noticed that intensive noise in a wrong time and a wrong place is generating frustrating feelings. *'I don't know, maybe not, it can be that sometimes but hard to say.' (E1) 'For sure, it's annoying when, at times, the noise level goes high and everyone speaks out loud.' (E3)* One of the teachers rated herself more sensitive to noise than many other people. *'Nowadays very often. The noise, it starts to peeve quite easily … I think I am more sensitive to noise. At least if I compare to my colleagues.' (F5)* Two of the respondents reported to experience physical symptoms whilst some told that they are not physically affected by noise during the working day. *'Occasionally I have the feeling that my ears are burning.' (F6) 'At some days, in the end of the day, my voice is strained. And headache maybe.' (F5) 'Here, at school, I have never noticed anything coming like that.' (E3) 'No. I think I am clamorous myself.' (F4) 'No, I have not noticed at all.' (E1)* Notwithstanding, most of the teacher must use their efforts daily to maintain the noise at satisfactory level. *'Yes, with the bigger groups quite often.' (E1) 'Almost daily.' (E3) 'Yes, surely, every day it had to be said that now you should be little bit calmer or more quiet.' (F4)* The noise and even its physical and mental consequences are not seen as an adequate reason for sickness absence. *'No, it is not an option.' (F5) 'Occasionally it could be understandable, but it could not be constantly the solution. It needs to be identified and addressed the cause of the noise.' (F4)*

The loud noise in the classrooms is not rare. It is observed that noise levels are rising towards afternoon hours. The noise level is proportional to the number of pupils in classroom and inverse proportional to age of the pupils in the classroom. The study of Skarlatos and Manatakis (2003) reveals the same. It depends on the situation and the sensitivity of the teacher how the noise level is perceived. The physical symptoms occur but are less common than the frustrating and annoyance caused by the noise, which are also supported by the findings of Seetha *et al.* (2008).

As a conclusion, it seems that the emotional, social and physical aspects in both educational units are in proper condition. The overall occupational stress levels among the teacher are low, even though there are individual stressors. However, the noise is seen as an influential factor in the educational environment. To keep the noise levels low enough takes time from the actual teaching and produces frustrating feelings.

In addition to the work-related issues, all the interviewees stated that they do not have significant concerns beyond the work that could be expected to affect the HRV. The uniform and low level of the stressors is optimum for the study, when the purpose is to investigate the effects of the noise level as a stressor on teachers' HRV.

3.2. Classroom noise and heart rate variability of the teachers

The noise levels of the classrooms are changing irregularly within the day and the week, which is noticable from the physically measured data, also. There are nconsiderable differences in the basic level of the noise in the classrooms of different teachers. Contrary to the interviewees' opinions, the higher noise level towards the end of the working day and towards the end of the week meaning that the noise level should be lower in the mornings than in the afternoons and on Mondays than on Fridays, cannot be seen from any measured noise data set. Instead, the physical noise level measurements targeted with the information from the timetables mainly reveal the same than reported by teachers: lessons with fewer pupils make less noise, upper grade pupils are more quiet than lower grade pupils, and for example, a reading lesson is more silent than a group work lesson.

The function of the heart rate monitor is based on the detections of so-called R-peaks, which are part of the electrical activity of the heart, see Figure 2. in Chapter 1.3. The recorded data contains the information about the time intervals between adjacent heart beats, called as RR-intervals. Some artefacts or outliers occur in the HRV data, most probably because of the weak contact of the sensor causing additional identifications of R-peaks and as well as undetected beats. Thus, the preprocessing is important part of the analysis. If the time between two successive intervals differs too much, it is presumable that one or more R-peaks are undetected. In turn, if the interval is very short, the extra peak is detected. The z-value threshold is set to identify the excessive gaps as well as too small ones and an interpolation algorithm is used to replace the outliers with the estimated values.

The preprocessed data is used to evaluate the heart rate (HR) and the heart rate variability (HRV). Density functions and power spectrum densities (PSD) are calculated for given time intervals. The noise data is used as a criterion to the selection of the analysis intervals. The assumed time periods, such as lunch times or other breaks, when the teacher is elsewhere than in the classroom, are rejected from the analysis. The changes in the noise level and in the HRV level are considered to be the main factor, and the important issue to consider, instead of the absolute values of the measured quantities.

A representative data set of the participant *E3,* see Table 3. in Chapter 2.2., is shown in the Figure 3. The highlighted areas are concerned to be relevant for the analysis based on the observations on the noise data. At the top of the figure are shown the PSDs of the HRV and the histograms representing the HR densities. Three large subplots (panels) in the bottom of the figure indicates the noise level, the HRV and the HR.

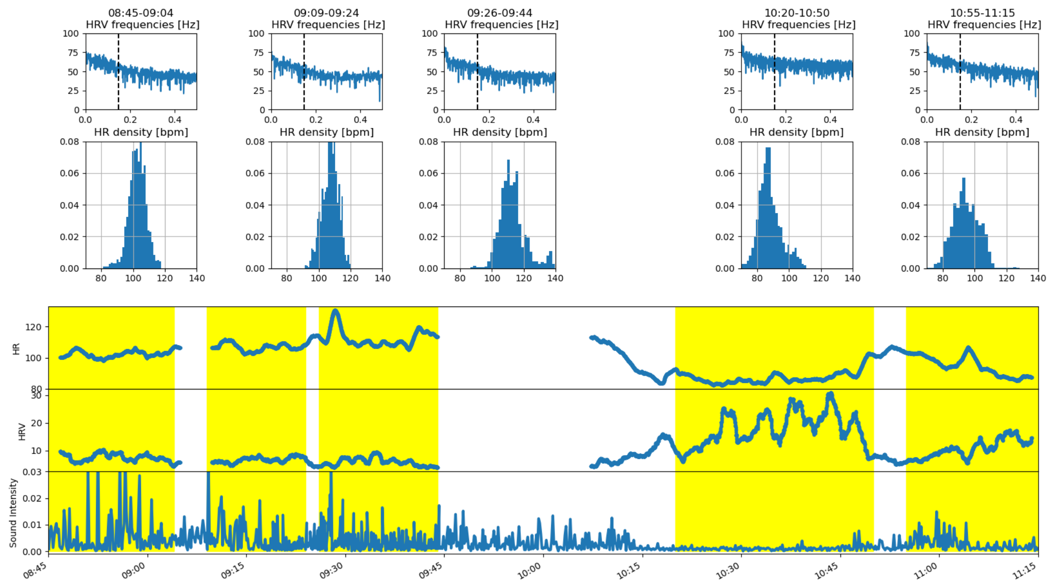

Figure 3. The graphs of the noise level, the HRV and the HR, and the power spectrum densities of the HRV and the density functions of the HR in given time intervals of the participant *E3*

The HRV data of the *E3* have an association to the physical noise data of the classroom. The level of the HRV is markedly lower, when the noise level is higher and more inconstant. It is also noticeable, that there is stronger fluctuation in amplitude at very low frequencies, about ten times in hour, in the HRV signal, when the noise is low. Based on the power spectrums it is observed that the HF component, the frequency band 0.15 - 0.4 Hz, is decreased, when the noise levels are higher compared to time window, when the noise is low. When the high noise level is seen as a stressor, the findings support the theory of the HRV, see Table 2. in Chapter 1.3.1. However, it has to be considered is the increase in the HRV entirely due to a lower than normal noise level or is there contribution via decreased heart rate for other reasons.

The correspondence data set of the participant *E1* is shown in the Figure 4. It is more difficult to say is there connections between the noise level and the HRV. The overall noise of the classroom is lower than in case with the participant *E3*, and the differences between distinguishable levels are not so distinct. The low frequency fluctuation is seen throughout the data, even though the amplitude is higher towards the end of the data set. From the power spectrum no associations are observed between the HRV and the noise level.

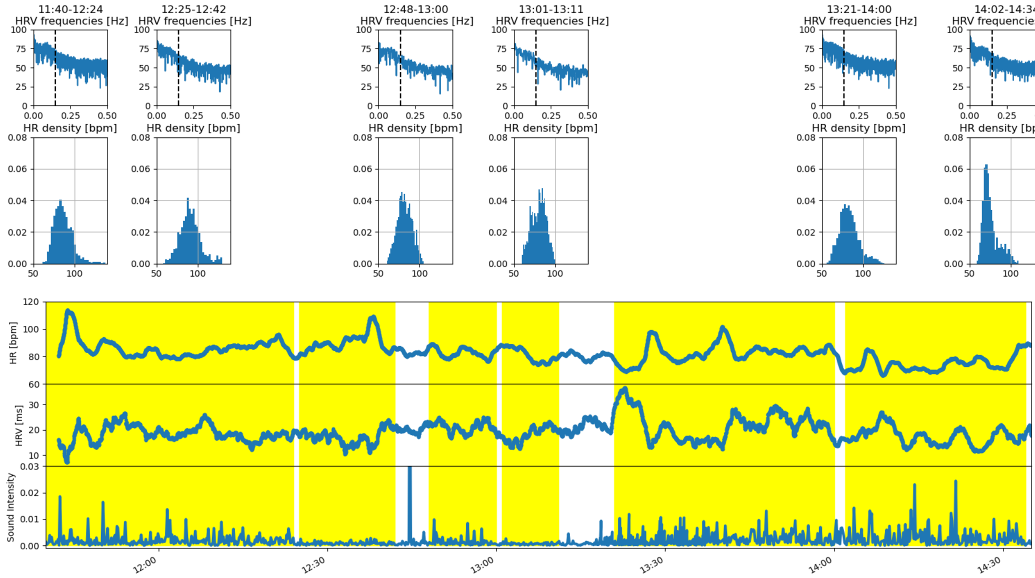

Figure 4. The graphs of the noise level, the HRV and the HR, and the power spectrum densities of the HRV and the density functions of the HR in given time intervals of the participant *E1*

The sample data concerning the participant *E2* is shown in Figure 5. The classroom noise is markable all the time. In the beginning of the sample period, association is found between the noise level and the HRV. The HRV is growing when the noise level drops. The gradient is same than the theory suggests: the lowered stressor, such as noise in this case, indicates increased the HRV. Later on, the noise is staying on the same level or even slightly rising, but for unknown reason, the HRV is still increasing, which is against the assumption. However, after a while the HRV returns to lower level whilst the noise level is remaining quite high. No associations are observed between the power spectrum and the noise level for this data either.

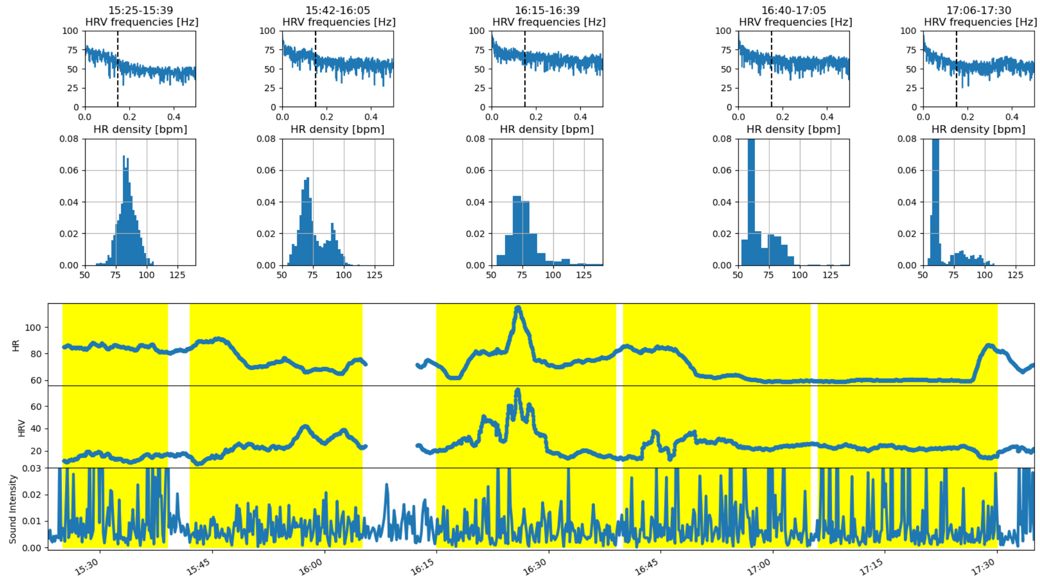

Figure 5. The graphs of the noise level, the HRV and the HR, and the power spectrum densities of the HRV and density functions of the HR in given time intervals of the participant *E2*

It is found a connection between the high noise level and the low values of the time-domain parameter of the HRV, the square root of the mean squared difference between adjacent RR-intervals (RMSSD). Several different lengths for the time window from five to hundred second were tested. The clear connection stayed visible until the window length was exceeding 30 seconds. In the Figures 6.-8. are the scatterplots of the participants *E3*, *E1* and *E2*, respectively, with five second window length. The noise level is in x-axis and the RMSSD value in y-axis.

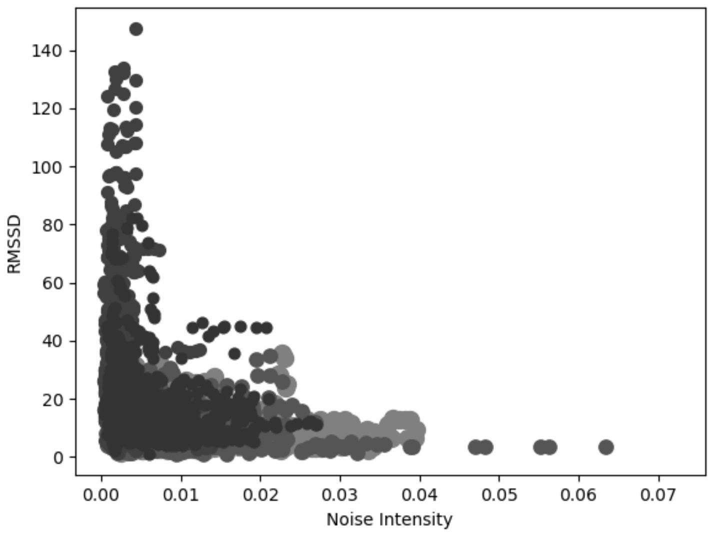

Figure 6. The scatterplot of the data of the participant *E3*. The noise level is in x-axis and the RMSSD values in y-axis.

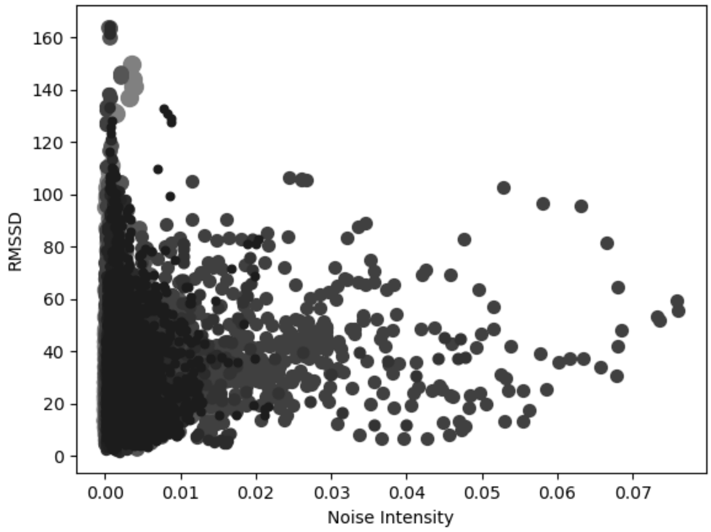

Figure 7. The scatterplot of the data of the participant *E1*. The noise level is in x-axis and the RMSSD values in y-axis.

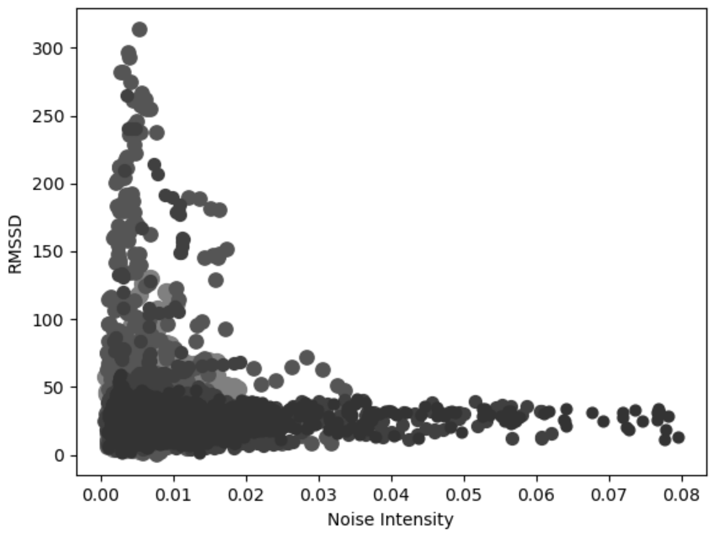

Figure 8. The scatterplot of the data of the participant *E2*. The noise level is in x-axis and the RMSSD values in y-axis

For each participants the RMSSD gets values for a wide range in the low noise levels. It is remarkable, that in the higher noise levels the RMSSD values are remaining noticeably lower, for some participants very clearly. Once more, these results support the theory: higher stress, which means higher noise in this case, indicates decreased values of the RMSSD.

3.3. Managerial decisions for preventing occupational stress

Loud classroom noise occurring in wrong time and place is perceived annoying and arouses a feeling of frustration among teachers, according to the interviews. The physical symptoms are observed rarely and only by some teachers. However, keeping the classroom noise appropriate requires efforts from all the teachers almost on a daily basis. These findings are in consistent with the study of Eysel-Gosenpath *et al.* (2012).

From the physical measurements are found associations between the classroom noise level and teachers' HRV, especially the association is clearly visible with calculated time-domain coefficient RMSSD. Data subsets display that in the lower noise levels the RMSSD is wide ranged of values, but in the higher level of the classroom noise, the value range is narrowed, RMSSD with only lower values. Because the noise is considered as a stressor, finding is in concordance with the previous studies and theory: increase in stress decreases the HRV (Castaldo *et al.* 2015; Kraus *et al.* 2013; El Aarbaoui, Chaix 2020).

As found on this study, and verified in the literature, unwanted noise occurs in classroom situations and it increases teachers' occupational stress and affects teachers' well-being and work performance. Supported by this study, the effects of the classroom noise are observable in the HRV.

The management of the occupational stress and the well-being plays a substantial role in the educational units. Teachers' well-being should be one of the core values. In order to get a reliable view of the current situation, to support the progress and to see the results of the improvements, it is necessary to quantify the level of occupational stress and the well-being. Regular measurements are essential for preventive actions; it is possible to address the grievances before they become bigger troubles. The difficulty is to find proper methods to assess the occupational stress and the well-being, in real-time enough to boost the managerial decisions. (Virolainen 2012) Beside the job satisfaction questionnaires, real-time measurements such as the HRV and the noise level measurements can give additional support for decision making.

Studies signify the importance of the indoor environment quality in the offices and equivalent working environments, such as educational units (Witterseh *et al.* 2004; Jahncke *et al.* 2011). Because the classroom noise is one of the essential stressors for the teachers, acoustic aspects should be considered already when designing the school environment. However, different organizational and technical noise control measures can be implemented afterwards in order to mitigate negative impacts whilst ensuring appropriate noise environment in the classrooms. Adequate floor space per pupil will reduce the overall noise, but it is not possible to provide more space unless a completely new building is constructed, or more space is rented. The smaller group size is one solution to maintain the noise level adequate enough at least in the lower grades. (Skarlatos, Manatakis 2003) In practice, to guarantee the optimal group sizes additional personnel are needed.

Teachers' working day at schools normally include break times but the possibility to spend them in a quiet place is not offered. Arranging a quiet chamber and opportunity to visit there during the day may relieve the stress and also the physical symptoms, such as headache and burning ears. Already a few-minute silence pause has a positive impact (Bernardi *et al.* 2006). Installation of acoustic walls or ceiling tiles to the classrooms eliminates adverse reflections and shortens the reverberation time whilst reducing the noise levels. The use of curtains and floor carpets as well as sound-absorbing materials in the furniture leads to further reductions. (Woolner, Hall 2010) Real-time noise monitoring with feedback, for example via coloured lighting or other visual feedback system, with adjustable limits according to the preference of the teacher can help to compensate the momentary changes in the noise level and to alleviate teachers' efforts. The systems help teacher to maintain the performance without interruptions and give the possibility to work at pleasant noise levels. (Van Tonder *et al.* 2015; Di Blasio *et al.* 2019)

The advantage of the automated real-time HRV measurement is that the stressful situations are identified early enough. Wearable HRV monitors such as smart watches and rings are reliable enough for the context simplifying the real-time management use further. Monitored data give the initiative to perform the preventive actions to lower the distress. Focusing on breathing, simple relaxation exercises or mindfulness-based solutions can help the teachers in an overloaded state. (Flook *et al.* 2013) On the other hand, the HRV measurements can cause ethical problems. Even if the purpose is to help the teachers to cope the stress during working, is the employer entitled to collect the information and insist for the actions, if needed. An objective way to perform the measurements is through the occupational health care, which can give the recommendations of the actions based on the results either on a personal level or uniformly for the whole work community. The best benefits are obtained when both the employer and the employee commit to this by providing opportunities and following guidelines, respectively.

3.4. Further considerations

The current study is based on fixed amount of data over restricted time period. According to the participants, it was incredibly hard to remember to robe the heart rate monitor every morning during the measurement period, as well as turn on the audio meter for the noise measurements. The same applied to making the written recording observations on a schedule-based form. For these reasons, some of the recorded dataset are only one or two hours per day, or either the HRV or the noise data, or both, are missing throughout the whole working day. The other problem related to the amount of the recorded data was the cell phone battery adequacy while using EliteHRV mobile application to store the HRV data. A separate mobile phone was purchased for the measurements, but it was not remembered to charge often enough, because it was no one's personal phone. In addition, there was difficulties to connect EliteHRV to SunDing heart rate monitor via the bluethooth, and the connection was disconnected for an unknown reason from time to time and did not boot until a new reconnection was made manually.

It is characteristics for the HRV being lower in the higher heart rate ranges. The activity of the measured person can be the contributing factor to the HRV, because it is likely but not necessary that the heart rate is higher in standing posture. For the reason the posture of the measured teacher should be taken account. In addition to other remarks, it would be worthwhile to obtain the information whether the teacher is mostly standing or sitting during the lessons to distinguish the contribution of the noise and the effect of the increased heart rate, because of standing, to the HRV.

To validate the associations between the measured noise level of the classroom and the HRV, and the self-evaluated stress levels of the teachers, there is a demand for the research containing more data in a form of more participants, longer monitoring periods and better measurement reliability. The objective observations during the lessons should be added to the physical measurements and the subjective evaluations to get more relevant data about the other factors than noise affecting to the HRV of the teacher in classroom situations, such as a posture of the teacher, type of the noise and the way of working. It is also possible to obtain the information about the posture using a separate accelerometer. Modern heart rate monitors have the accelerometer integrated, and the accelerometer data can be used in further analysis.

The current study focuses primarily on the effects of noise on teachers' HRV in fairly similar educational units. An interesting approach is to do the measurements in schools, which do not share the similarities, for example in large schools and smaller ones, urban schools and rural areas and schools from different countries. It would also be fascinating to compare the results of young teachers with older ones, more with less experienced teachers and whether gender affects the appearance of noise impacts on the HRV. Other compelling topic is to do the measurements in the perspective of the pupils and investigate the consequences of the classroom noise to the HRV and the learning outcomes of the pupils.

In addition to educational environment, the corresponding research with real-time noise level and employee's HRV measurements can be conducted, and the results applied in other similar occupational environments, where presumably should not be annoying noise but as a general it occurs, such as open-space offices with highly educated people.

CONCLUSIONS

The sound environment in Finnish educational units has experienced the alteration during the last decades. The teaching has transformed from teacher-driven lecturing to more interactive teaching process. At the same time, the classroom noise levels have risen. While the change is mainly desirable, it has also led to undesirable results. Exposure to the long-term noise has been found to be the contributing factor to the occupational stress of the teachers. Although the physical symptoms are rare, the inconvenience caused by noise are more or less daily.

The main research question is related to managerial decisions which can be done to improve the teachers' working environment in order to control the noise level in classroom. The perceived link between the noise level and the occupational stress and the work performance of the teacher will be additional support for the consistent decisions at management level. By paying attention to the technical and organizational solutions–for example in terms of the adequate acoustic in the form of acoustic tiles and other materials, the sufficient space of the working environment and the convenient size of the educational groups, which together will reduce the effects of the unwanted noise, educational units will move towards more productive environments. Notwithstanding the financial investments the cost-efficiency in educational sector will improve.

The purpose of this study is to clarify how the classroom noise levels and the heart rate variability (HRV) of the teachers can be measured objectively in real-time. The aim is to investigate, how the classroom noise influence teachers' HRV immediately or with very short delay. In addition, the impact of the noise on teachers' performance and occupational stress and well-being is evaluated.

The measurements are conducted in two Finnish primary schools as a case study. The schools are similar in the terms of the size, the physical environment and the working atmosphere. The uniformity of the schools is considered to be suitable for the context of the study. Altogether six volunteer teachers are participating. The noise level of the classroom is measured using hifi audio microphone. Simultaneously the HRV of the teacher is recorded with chest belt in real classroom situations. Teachers' attitudes towards the noise and the perceived impacts of the noise on occupational stress and performance is assessed via semi-structured interviews.

The methods used in this study are capable to measure the classroom noise level and the teachers' HRV objectively. The measured noise level reveals the same than the information via the semi-structured interviews: classroom noise level depends on the subject taught and the way of working, and it is proportional to the number of pupils in the classroom and inverse proportional to the age of the pupils. The association is visible between the physically measured noise level and the HRV of the teacher, especially with the RMSSD, the time-domain coefficient of the HRV: higher noise level indicates lower values of the RMSSD. According to the interviews, noise is causing frustration and annoyance to teachers occasionally. Physical symptoms such as vocal problems and headache are experienced, but less frequently. However, efforts are needed almost daily basis to maintain the classroom noise level satisfactory.

The findings of the current study are in correspondence with the scientific literature. The noise is considered as an essential factor when contemplated the occupational stressors affecting to teachers' well-being and performance. The effects of the stressors, as the noise in this context, can be observed as the changes in the heart rate variability.

Beside the educational environment, the results will provide significant guidelines for optimizing noise in the work environments of the highly educated employees in open-plan offices or similar places. The real-time measurements and ideas used in the current study can be correspondingly utilized to detect the situation and to ameliorate the noise ambience of the offices to improve employees' productivity.

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APPENDICES

Appendix 1. Semi-structured interview framework

DEMOGRAPHIC FACTORS

Age
Gender
Level of education
Work experience
Degree of teaching (primary school/secondary school/class teacher/subject teacher)

GENERAL

Is *teacher* your primary/only education/occupation?
What other educations/occupations you have?

Why did you decide to become as a teacher?
Which are the reasons you have continued as a teacher?
What it means to you to be a teacher?

Have you changed your working place (recently)? What were the reasons for the change?
Have you thought to change working place recently/ever? Why?
Have you changed the occupation? What were the reasons for the change?
Have you thought to change occupation? Why?

How do you feel in the mornings before the working day?
[Do you feel that it is nice to come to work? Do you feel that it is nice to be at work?]
How do you feel at the end of the working day? [Ok, satisfied, tired, frustrated…]
How much do you think about work-related things outside of working hours?
How much do you work outside of working hours?

WORKING ENVIRONMENT – EMOTIONAL

How would you describe the general atmosphere at your workplace?
How would you describe the relationships you have with your colleagues? With other coworkers?
How would you describe the relationship between you and your supervisor? How about the TASK Tuki ry?
How would you describe your attitude and relationships towards pupils/students? Their parents?
What suggestions for improvement do you have?

WORKING CONDITIONS – PHYSICAL

In what kind of condition are the classrooms in your school?
[space, lighting, temperature, air condition / air quality, acoustics…]

What things are good? What things need improvement? What suggestions for improvement do you have?
How much there is pupils in your class?
How do you feel about the group sizes?
What would be optimum number of pupils in one group? [Is there need for changes?]

How about the educational materials and equipment? What you have? [Are those updated, easy to use, widely available]

TEACHING

Is your work meaningful to you?
Do you like your work? What are the reasons for that??
Do you feel that you are good at your job? Why?

How would you describe your workload?
[Do you feel that your work is not enough/too much demanding / burdensome?]
What kind of expectations you have concerning your work? From whom are the expectations coming from?
What kind of support you get at work? From whom? [your supervisor/other teachers/colleagues in your working community or other teachers / colleagues / someone else outside of your community]
Is there a need for easier way to ask support? What kind of suggestions you have?

How do you describe the challenges/responsibility you have in your work? [Not enough/too much]
Have you thought, that you are wasting your professional resources recently/ever?
Could you give examples?

How much can you influence on your job description and the way you handle your job?
In what way you can influence?

Do you feel that your job makes sense?
Do you feel your work matters/your work is completely irrelevant?
Do you think you would achieve results you want/others want from you?
What makes you feel so?
How much does those matters for you at all?

What kind of things are frustrating you at work?
[- lack of time/resources/space/responsibility…]
What kind of things are giving joy and satisfaction?
How do you feel about the compensation? [alary and other benefits, is those in line with your job description and requirements]

NOISE

What is noise? How do you feel about it?
How you describe annoying noise? Pleasant noise? [Is there such a thing?]
How do you describe your feelings towards noise?

What kind of noise is in your classroom?
How often do you pay attention to the noise levels in your working space / classroom?
How the noise level is changing during the lessons?
How the noise is varying between classes (subjects)/groups?
How the noise level is varying between morning and afternoon hours or beginning/end of the week in your class?

How the noise levels impact on your work? [Your efficiency/well-being/teaching methods used/pupils' learning outcomes]

What kind of physical symptoms you have experienced when the noise levels increase (too high)? [Headaches/nausea/ringing in the ears/fatigue/restlessness]

What kind of mental symptoms you have experienced when the noise levels increase (too high)? [- lack of concentration/frustration/indifference/desolation/despair]

How do you feel after being in noisy classroom?
In what kind of situations are you more sensitive to noise?

Have you been on sick leave because of the physical/mental symptoms of the noise?
Have you considered sick leave because of the symptoms caused by excessive noise?
Do you think that excessive noise in itself is a good enough reason to apply sick leave?

OTHER STRESS FACTORS

Are there other stressors in your life right now? Do you feel that they are significantly larger than the burdens related on your work?

(The aim is not to ask and find out, what the other factors are, but to note, that there may be something to consider when analyzing the measurements, such as the HRV measurement)

Appendix 2A. Preprocessing the noise data

The noise level of the classroom is recorded using the Python script shown below. The script is based on PyAudio module and parallel paradigm. It utilizes two threads, other to record the sound in 10 sec chunks, other to apply the Fast Fourier Transformation and store the frequencies. The data is saved to a folder created by the timedate (hour, day, month) into Raspberry Pi. The data can easily be sent to a cloud but for the reason of short study period, it was not implemented to this code.

To ensure that the script runs properly, Unix crontab and flock is used to check every three minutes if the script is running; if not, it will be restarted.

```
#!/usr/bin/env python3

import pyaudio
import multiprocessing
import numpy as np
import time
from pathlib import Path

audio = pyaudio.PyAudio() # create pyaudio instantiation

info = audio.get_host_api_info_by_index(0)
numdevices = info.get('deviceCount')
for i in range(0, numdevices):
        if (audio.get_device_info_by_host_api_device_index(0,
i).get('maxInputChannels')) > 0:
                print( "Input Device id ", i, " - ",
audio.get_device_info_by_host_api_device_index(0, i).get('name') )



form_1 = pyaudio.paInt16 # 16-bit resolution
chans = 1 # 1 channel
samp_rate = 44100 # 44.1kH z sampling rate
chunk = 4096 # 2^12 samples for buffer
record_secs = 10 # seconds to record
dev_index = 2 # device index found by p.get_device_info_by_index(ii)


# create pyaudio stream
stream = audio.open(format = form_1,rate = samp_rate,channels = chans, \
                    input_device_index = dev_index,input = True, \
                    frames_per_buffer=chunk)

print("recording")
frames = []

#
```

```
# 1. thread to analyze (do the FFT) and save the data
#

def saveFFT(data, name, ddate, dhour):
        N = data.size
        Nper2 = int(N/2)-1
        fourier = np.fft.fft( data/32768.0 )[0:Nper2]

        Path("/home/pi/fft/" + ddate + '/' + dhour ).mkdir(parents=True,
exist_ok=True)
        np.save( '/home/pi/fft/'+ddate+'/'+dhour+'/'+name+'.npy', fourier )

#
# 2. Main loop to listen the mic and start thread (if possible)
#
while True:
        # loop through stream and append audio chunks to frame array
        startTime = time.strftime("%Y%m%d-%H%M%S")
        ddate = time.strftime("%Y%m%d")
        dhours = time.strftime("%H")
        frames = []
        for ii in range(0,int((samp_rate/chunk)*record_secs)):
                data = stream.read(chunk, exception_on_overflow = False)
                frames.append(data)

        npdata = np.frombuffer(data, dtype=np.int16)/32768.0
        p = multiprocessing.Process( target=saveFFT, args=[npdata, startTime,
ddate, dhours]  )
        p.start()

print("finished recording")
# stop the stream, close it, and terminate the pyaudio instantiation
stream.stop_stream()
stream.close()
audio.terminate()
```

The 10 seconds Fast Fourier Transformation files of the sound pressure is combined into one large file including the measurements of noise for one day.

```
import os
import numpy as np
from datetime import datetime

date = datetime.strptime( '2020-03-19', '%Y-%m-%d' )
path = 'C:\\Users\\marjoleino\\Documents\\python\\datascience\\thesis\\fft\\'
path +=  date.strftime("%Y%m%d")

files = []
# r=root, d=directories, f = files
for r, d, f in os.walk(path):
    for file in f:
        if '.npy' in file:
            files.append(os.path.join(r, file))
```

```
ts = np.array([])
freqs = np.zeros( shape=(2047,))


for f in files:
    print(f)
    n = f.rfind('\\')
    t = f[n+1:-4]
    #Convert datetim string to correct format
    t1 = t[:4] + '-' + t[4:6] + '-' + t[6:]
    t2 = t1[:10] + 'T' + t1[11:13] +':'+t1[13:15]+':'+t1[15:]
    ts = np.append(ts, t2)
    #print(ts)
    A = np.load( f )
    freqs = np.vstack( (freqs, A) )


np.savez( date.strftime("%Y%m%d") + '.npz', t=ts, f=freqs)
```

Appendix 2B. Preprocessing the HRV data

The HRV data obtained from SunDing SD-520 via Elite HRV application contains only the difference of successive R-peaks. The data need to be preprocessed because of the artifacts most probably due the improper sensor contact. The data is polluted by outliers. First, a few different methods are tested to identify and remove or fix the outliers. The z-score method with a window of 8 datapoints is found to be sufficient.

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

# https://stackoverflow.com/questions/59596912/rolling-z-score-applied-to-
pandas-dataframe/59597003#59597003
def zscore(x, window):
    r = x.rolling(window=window)
    m = r.mean().shift(1)
    s = r.std(ddof=0).shift(1)
    z = (x-m)/s
    return abs(z)

window = 8
N = 100
dNstr = 3
xval = np.arange(N)
yval = 5*np.sin(0.01*xval) + np.sin(0.3*xval) +  0.5*np.sin(2*xval)
for i in np.random.randint(N-1, size=7):
    yval[i] = yval[i]*10

df = pd.DataFrame( yval, columns={'orig'})
df['mean']= df.orig.rolling(window).mean()

roll = df.orig.rolling(window)
df['zvalue'] = abs( ( df.orig - roll.mean() )/ roll.std() )

#
df["zscore"] = zscore(df.orig, window)
df["zscoreRem"] = df.orig[ df.zscore < dNstr ]
df["zscoreI"] = df.zscoreRem.interpolate() - 1

#
df['median']= df['orig'].rolling(window).median()
df['std'] = df['orig'].rolling(window).std()

#filter setup
df["filtered"] = df.orig[(df.orig <= df['median']+dNstr*df['std']) & (df.orig
>= df['median']-dNstr*df['std'])]
df.filtered = df.filtered.interpolate() - 2


df[['orig', 'zscoreI', 'filtered']].plot( ylim= [-10,15], label='Original')
```

In addition to the automated outlier rejection, some clearly misbehaved datapoints are rejected by visual inspections. Finally, the preprocessed one-dimensional data is converted into Pandas timeseries consisting of time and respective RR interval.

```
import os
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

from datetime import datetime, timedelta


dNstr = 2
window = 10

def main():
    file = "markku\\20200319T161003.txt"

    path =
'C:\\Users\\marjoleino\\Documents\\python\\datascience\\thesis\\hrv\\'
    path +=  file

    if ".txt" in file:

        df = loadFile( path )
        #abs( pd.orig.diff() ).hist(bins=100).

        smoothHRV( df )
        manualFix( df, file )

        fig = plt.figure()
        df.zscoreI.plot(marker='o')
        fig.canvas.mpl_connect('button_press_event', onclick)

        df = changeIndex(file, df)

        #Save it
        df.to_pickle( file.replace('\\', '_')[:-4] + '.pickle' )

    else:
        # r=root, d=directories, f = files
        for r, d, f in os.walk(path):
            for file in f:
                if '.txt' in file:
                    print( file )


def changeIndex(file, df):

    ind = file.find('\\')
    times = datetime.strptime(file[ind+1:-4], '%Y%m%dT%H%M%S')
    diffSecs = (times-datetime(1970,1,1)).total_seconds()
    df['dateTime'] = (pd.to_datetime( df.zscoreI.cumsum(), unit='ms' )) +
timedelta(seconds=diffSecs)
```

```
    #The original.
    df = df.iloc[window:]

    df.set_index('dateTime', drop=True, inplace=True)
    df.index = pd.to_datetime(df.index)

    return df

def onclick(event):
    if event.dblclick:
        ix, iy = int(round( event.xdata )), int(round(event.ydata))
        print("pd.zscoreI.iloc[%d]=%d"%(ix,iy))

def manualFix( pd, file):
    if file == "markku\\20200302T090621.txt":
        pd.zscoreI.iloc[16]=773
        pd.zscoreI.iloc[53]=666
        pd.zscoreI.iloc[98]=671
        pd.zscoreI.iloc[140]=599
        pd.zscoreI.iloc[182]=725
        pd.zscoreI.iloc[185]=667
        pd.zscoreI.iloc[202]=930
        pd.zscoreI.iloc[208]=804
        pd.zscoreI.iloc[215]=699
        pd.zscoreI.iloc[819]=721
        pd.zscoreI.iloc[2410]=626
        pd.zscoreI.iloc[2412]=663
        pd.zscoreI.iloc[2413]=721
        pd.zscoreI.iloc[2414]=775
        pd.zscoreI.iloc[2416]=712
        pd.zscoreI.iloc[2440]=498
        pd.zscoreI.iloc[2757]=831


    elif file == "markku\\20200312T082437.txt":
        pd.zscoreI.iloc[96]=531
        pd.zscoreI.iloc[98]=519

def zscore(x, window):
    r = x.rolling(window=window)
    m = r.mean().shift(1)
    s = r.std(ddof=0).shift(1)
    z = (x-m)/s
    return abs(z)

def smoothHRV(df):
    df["zscore"] = zscore(df.orig, window)
    df["zscoreRem"] = df.orig[ df.zscore < dNstr ]
    df["zscoreI"] = df.zscoreRem.interpolate()

    #Delete some of the tool columns
    del df['zscoreRem']
    del df['zscore']

def loadFile(file):
    data = np.loadtxt(file)

    return pd.DataFrame( data, columns={'orig'})
if __name__ == "__main__":
    main()
```

Appendix 2C. RMSSD, STDRR and noise

The associations between the statistical parameters of HRV such as RMSSD and STDRR and the noise are plotted in the scatter plot. Also, the causal lag is taken into account. Only the highlighted parts are considered.

```
import os
import numpy as np
import pandas as pd
from functools import reduce
import matplotlib.pyplot as plt
import matplotlib.dates as md

from datetime import datetime, timedelta
import itertools

dNstr = 2
window = 10

def main():
    anal = "T2_20200312" #Sound
    dt = ['08:25', '14:35']
    path = 'C:\\Users\\marjoleino\\Documents\\python\\thesis\\'


    #The sound file.
    npz = np.load( anal + '.npz')
    ts = npz['t']
    times = [datetime.strptime(t, '%Y-%m-%dT%H:%M:%S') for t in ts]

    dfFreqs = pd.DataFrame(npz['f'][0:-1],      # values
              index=times)     # 1st column as index)  # 1st row as the column
names

    dfs = []
    for r, d, f in os.walk(path):
            for file in f:
                if anal in file:
                    if '.pickle' in file:
                        dfs.append( pd.read_pickle(file) )
                        print( file )

    dfFre = pd.DataFrame( abs(dfFreqs.between_time(start_time=dt[0],
end_time=dt[1]).sum(axis=1)) \
                         .resample('1S').interpolate(method='linear'),
columns=["Intensity"] )
    dfFre.index.names = ['dateTime']

    #print("dfFre:")
    #print( dfFre )            #OK
    #print( dfFre.index )

    df = pd.concat( dfs )    # orig and zscoreI are times in between RR peaks
    dfRR =  pd.DataFrame( df.zscoreI.between_time(start_time=dt[0],
end_time=dt[1]).resample('1S').mean() )
    dfRR = dfRR.rename(columns={'zscoreI': 'RR'})
```

```
    result = pd.merge(dfFre, dfRR, on='dateTime')

    # Plot the statistical measures on RR
    fig = plt.figure()
    for n, x in enumerate( itertools.product([-50, -100, -300], [4, 20, 40])
):
        window = x[1]
        lag = x[0]
        result = stats( result, window, lag)

        # Plot the things
        ax=plt.subplot(3,3,n+1)
        plotIt( result, anal, window, lag, ax )

        #The correlation  #pandas.DataFrame.corrwith
        #C = result.rolling(window=window).corr()
        #C.plot()

def loadFile(file):
    data = np.loadtxt(file)
    return pd.DataFrame( data, columns={'orig'})

def stats( result, window, lag ):
    # Lagged statistical values.
    #https://medium.com/@NatalieOlivo/use-pandas-to-lag-your-timeseries-data-
in-order-to-examine-causal-relationships-f8186451b3a9

    #0. Average of the sound
    result['SoInt'] = result.Intensity.shift(lag).rolling(
window=window).mean()

    #1. stdRR: the standard deviation
    result['stdRR'] = result.RR.rolling( window=window ).std()

    #2. rmsSD: sum of difference of peaks squared, and normed
    SD = (result.RR.diff())**2
    result['rmsSD'] = (SD.rolling( window=window ).mean())**0.5

    #3. HRV: |diff| of the RR
    result['hrv'] = (abs( result.RR.diff() )).rolling( window = window
).mean()

    return result


def plotIt(result, anal, window, lag, ax):
    pData = []
    if "T2_20200312" in anal:
        pData.append( { 'st':'08:30', 'et':'08:42'} )
        pData.append( { 'st':'08:43', 'et':'09:01'} )
        pData.append( { 'st':'09:02', 'et':'09:27'} )
        pData.append( { 'st':'09:41', 'et':'10:00'} )
        pData.append( { 'st':'10:49', 'et':'10:58'} )
        pData.append( { 'st':'11:40', 'et':'12:24'} )

        pData.append( { 'st':'12:25', 'et':'12:42'} )
        pData.append( { 'st':'13:00', 'et':'13:11'} )
        pData.append( { 'st':'13:21', 'et':'14:34'} )
    elif "T3_20200311" in anal:
```

```
        pData.append( { 'st':'08:45', 'et':'09:04'} )
        pData.append( { 'st':'09:09', 'et':'09:24'} )
        pData.append( { 'st':'09:26', 'et':'09:44'} )
        pData.append( { 'st':'10:20', 'et':'10:50'} )
        pData.append( { 'st':'10:55', 'et':'11:15'} )


    for j,i in enumerate( pData ):
        result.between_time(start_time=i['st'], end_time=i['et']). \
            plot.scatter(x = 'SoInt', y='rmsSD', ax=ax, c=(1/(j+1), 1/(j+1),
1/(j+1), 1), s=200/(j+1))

    ax.set_title('Window: ' + str(window) + ', lag: ' + str(lag))

if __name__ == "__main__":
    main()
```

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