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# INFLUENCE OF ACOUSTIC ENVIRONMENT UPON WORK PERFORMANCE IN OPEN-PLAN OFFICES

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## ABSTRACT

The recent tendency of having employees work in common spaces has brought to our attention a long list of problems such as concentration and efficiency issues of working groups in large companies. This can result in health disorders, high levels of stress in the workplace and a loss of concentration. The aim of this study is to establish a correlation between different acoustic environments and the performance of the workers, based on their creativity.

One open-plan architectural office was selected for the research. Recordings of the real time acoustic environment have been executed on site both during working hours and during the weekend without the employees. In order to analyze the variation of creativity for the selected individuals on the premises, Torrance-based tests have been designed and given to the participants in three defined stages: 1<sup>st</sup> – ambient noise without ventilation, 2<sup>nd</sup> – ambient noise with ventilation, 3<sup>rd</sup> – real working environment recordings, including speech intelligibility, reproduced on headphones. The results are analyzed in order to reveal the parallel between creativity and different acoustic environments in the open-plan office.

## 1. INTRODUCTION

There are key factors that contribute to the perception of comfort in an open-plan office, such as thermal comfort, lighting and acoustics. According to recent studies, work performance can decrease due to poor acoustic conditions and mostly due to intelligible speech. Results show that “office-related” or cognitive tasks, namely memory for words, information search, math, word fluency, procedure and statistical analysis are significantly affected by speech [1]. Hongisto [2] presents a function, explaining the correlation between STI and the performance of some cognitive tasks.

However, when analyzing an open-plan office we must take into consideration the work process and the people involved. As stated by Sarwono [3] the acoustic conditions of an OPO can be improved by only modifying the workstation layout. One type of layout is more suitable for private working office, where more concentration is needed, and another one is suitable for people working in groups.

With the growing development of software programs and the optimizations appearing in most work tasks in the present-day world, most manual work tasks

are being substituted with simple programming scripts. This natural evolution leads to more creative work tasks left for the employees. The aim of this study is to find the interdependency between the acoustic environment in the open-plan office and the creativity of the individuals.

Creativity is found in every field of human endeavor, in every discipline, and in every profession, and it is also appreciated as a stimulus for social and economic growth [4-5]. The Torrance Tests of Creative Thinking (TTCT) have been the standard for assessment of creative thinking abilities since it was first published in the mid-1960s [4]. A considerable drawback of the TTCT is the required time for completing the verbal and figurative tasks. Several abbreviated forms have been adapted for working with adults, which lead to the development of the Abbreviated Torrance Test for Adult (ATTA) [6], that is the current instrument adapted for evaluating creativity in this study.

Another study [7] explores how ambient noise, an important environmental variable, can affect creativity. For conducting the experiments in [7] Remote Associates Test (RAT) have been used and the acoustic environments have been created by electronically superimposing independently recorded multi-talker noise in a cafeteria, a roadside traffic, and a distant construction noise, with the idea of creating a soundtrack of constantly varying background noise [7]. Our research stands out because we use real working environment recordings that recreate binaural sound perception in different conditions and not artificially manipulated sound, white or pink noise. Moreover, the RAT that was used in the research of [7] consisted only of verbal items, while in our study the ATTA includes figural items, contributing further to the understanding of creativity.

## 2. METHODOLOGY

### 2.1 Measurements on Site

The case study consists of three main phases, beginning with defining the acoustic parameters of the chosen open-plan office, measured according to the latest standard ISO 3382-3:2012 and categorized based on the study of Virjonen [8-9]. Site measurements have been conducted during off working hours in order to record and analyze reverberation time  $T_{30}$ , distraction distance  $rD$ , privacy distance  $rP$ , background noise levels and Speech Transmission Index (STI) for 3 different workstation positions in the open space. For the measurements the following equipment was used:

- Reference microphone iSEMcon model EMX-7150
- Sound card Behringer, U-PHONORIA UMC204HD
- Loudspeaker F&D model F550X
- Software Arta and EQwizard

## 2.2 Audio Recordings

The second phase consisted of conducting audio recordings both during on and off working hours. The main goal was recording three different acoustic environments, in order to reproduce them as simulated binaural sound perceptions for the creativity testing.

All of the recordings had the same duration of 10 minutes. The three Torrance tests were adapted for the length of the recordings accordingly. Two of the recordings were conducted during off working hours – 1<sup>st</sup> – ambient noise without ventilation and 2<sup>nd</sup> – ambient noise with ventilation. For the 3<sup>rd</sup> – real working environment, including speech intelligibility, the recordings were conducted during the afternoon of a working day.

## 2.3 Creativity Tests

The final phase included three volunteers from the open-plan office, chosen for their dispersed positions as shown on Figure 1. Every participant took a 10 min creativity test under the impact of each of the audio recordings. The aim was to analyze the results and make a comparison between the tests for every position and see how the creativity of each individual changed during the simulations.

## 3. OPEN-PLAN OFFICE

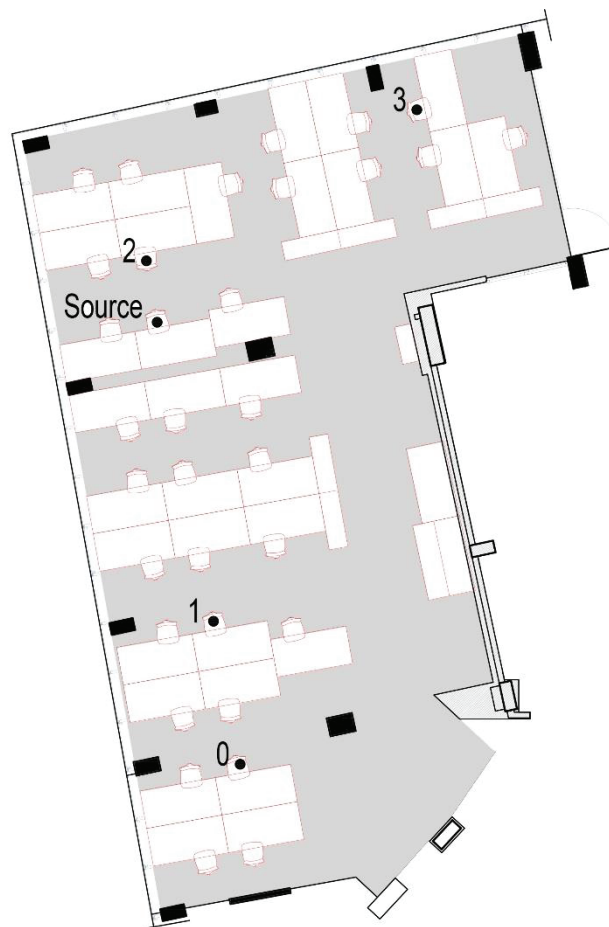
When analyzing the effects of the acoustic environment in open-plan offices, most of the already executed experiments are based on work-related tasks, focusing mainly on cognitive functions and concentration. However, the growing number of start-up and software developing companies requires employees to develop adaptational and innovational skills which are linked to creativity. Moreover, open-plan design offices are being occupied by different professionals, such as graphic designers, marketing specialists, architects, etc. All of the above include creative design stages in their day-to-day work.

For conducting this case study an architectural office was selected. All of the occupants in the open-plan office are architects and are familiar with the office environment. In Table 1. the space parameters are shown, while Figure 1. pictures the layout and the examined working stations for the experiment.

Parameter	Value
Volume	351m <sup>3</sup>
Area	135m <sup>2</sup>
Height	2.60 m
Workstations	34
Average Dist. between desks	1.50m

Average Dist. between points	7.10 m
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**Table 1.** Characteristics of the selected open-plan office.



**Figure 1.** Layout of the open-plan office and positions of the selected workstations.

## 4. ABBREVIATED TORRANCE TEST FOR ADULT (ATTA)

The adapted ATTA that was used in the experiment consisted of two verbal (Activity #1, Activity #2) and two figural items (Activity #3, Activity #4). For the different tasks, the separate norm-referenced assessments are accordingly [10]:

-Figural – fluency, originality, abstractness of titles, elaboration, resistance to premature closure

-Verbal – fluency, flexibility, originality

The evaluation of the verbal and figural items is done separately. Furthermore, for understanding the creativity from the figural items, another 13 creative strengths had to be analyzed for every test [10]. The Composite Assessments of Creativity for the figural items consists of Average Standard Score (ASS) and Creativity Index (CI). The Creativity Index is calculated by adding the scores from the thirteen criterion-referenced indicators and the ASS. This index is perhaps the best measure to reflect the overall level of creativity. For the verbal items, the Composite Assessment of Creativity is the Average Standard Score (ASS).

The check list of creative strengths (that can be found in the participants' drawings) includes:

- Emotional Expressiveness (in drawings, titles)
- Storytelling Articulateness (context, environment)
- Movement or Action (running, dancing, flying, falling, etc.)
- Expressiveness of Titles
- Synthesis of Incomplete Figures (combination of 2 or more)
- Synthesis of Lines (form A) or Circles (form B) (Combinations)
- Unusual Visualization (above, below, at angle, etc.)
- Internal Visualization (inside, cross section, etc.)
- Extending or Breaking Boundaries
- Humor (in titles, captions, drawings, etc.)
- Richness of Imagery (variety, vividness, strength, etc.)
- Colorfulness of Imagery (excitingness, earthiness, etc.)
- Fantasy (figures in myths, fairy tales, science fiction, etc.)

### 5. ACOUSTIC ENVIRONMENT

When conducting the acoustic measurements, we took into account the volume, size and location of the desks in the office. Four points were selected, in which measurements of reverberation time in an empty office were made. Three of the points coincided with the points in which the recordings and tests were made. The fourth point was selected farthest from the source to more accurately account for the distraction index  $rD$ . The measurements of the reverberation time of the individual points are presented in Figure 2. below.

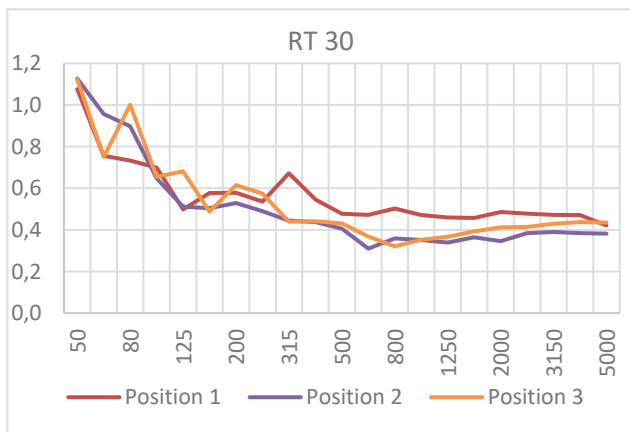


Figure 2. The measured  $T_{30}$  for each position 1-3.

The average  $T_{30}$  calculated from all three positions in the frequency range 50-5k Hz are shown in Table 2.

	Reverberation time RT60	Breem Standard
Position 1	0.56	<0.8
Position 2	0.50	<0.8
Position 3	0.53	<0.8

Table 2. Average  $T_{30}$  for each position 1-3.

In order to calculate distraction and privacy distance, STI measurements were made at the three selected points in the office using male speech spectrum. The measured results are presented in Table 3.

	Position 2	Position 1	Position 0
STI	0.89	0.74	0.63
Distance [m]	1.3	6.38	9.74

Table 3. STI and Distance from source for each point.

Interpolating the obtained results, a graph shown below in Figure 3. indicates how the STI parameter alters with increasing distance.

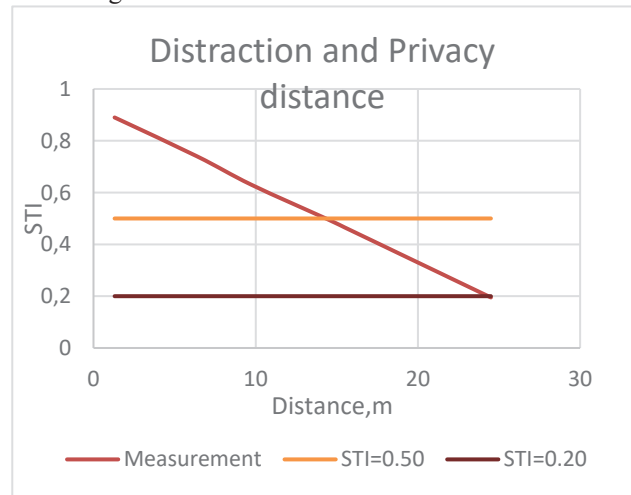
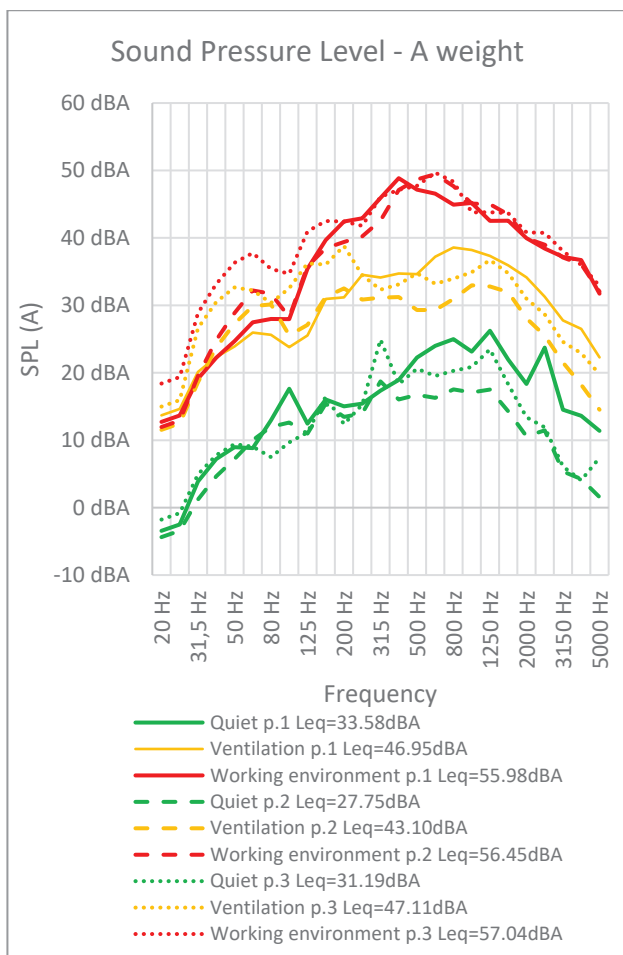


Figure 3. STI referring to source distance.

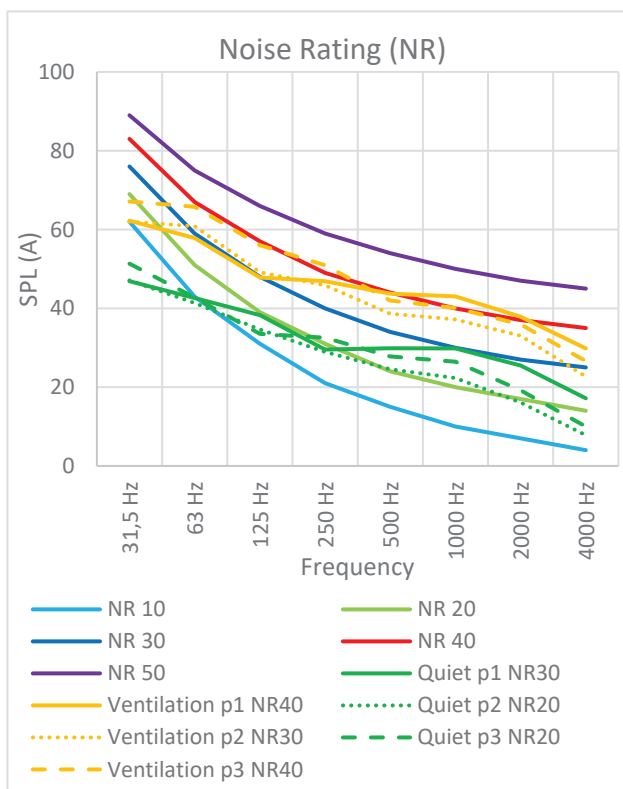
The calculated results for the distraction index show that  $rD > 14.5m$ , which places the office in category D according to the study of Virjonen, EN ISO Standards and Bulgarian national regulation №6 [8-11].

An analysis of the audio recordings was also made, taking into account the sound pressure level of each recording at each point in 1:3 octave band on the curve of  $A_{weighted}$ . The results of the absolute sound pressure level in quiet and ventilated environments are shown on the noise graph rating (NR) curve.

According to the measured acoustic parameters, the reverberation time of all points satisfies the requirements. The sound level of the background noise with the ventilation on is normal and meets the requirements of NR40 and NR30 but is still high. The lack of barriers between the workstations is why the office is categorized as Class D according to the standard. As a consequence, the sound level in the work environment is higher by 6 dB than the permissible national standards.



**Figure 4.** Sound pressure level – A weighted for all positions and all environments as measured.



**Figure 5.** Noise Rating evaluation of quiet and ventilation environments.

## 6. AUDIO RECORDINGS

Audio recordings were made at each position with specialized binaural instrumentation, which allows the signals to be reproduced to the listener as realistically as possible-Figure 6.

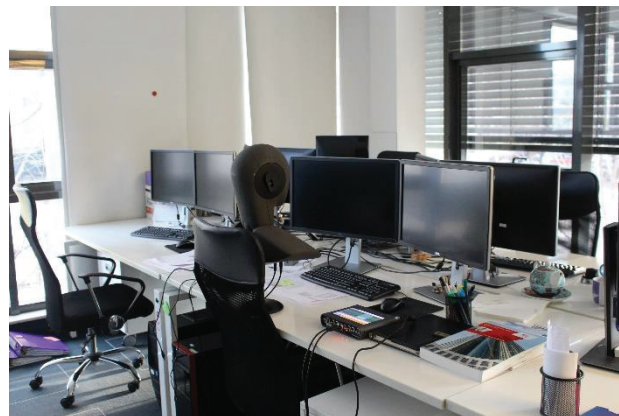
All recordings were carried out using HEAD acoustics equipment: HSU III.2 calibratable artificial head with ICP microphones for binaural recordings and BHS II binaural recording headsets connected to Squadriga III / SQobold mobile front ends.

Playback equalizer labP2 from the company HEAD acoustics together with closed headphones with active noise cancelling (HD NC) were used for the listening tests.

The recording was made in three different environments. The first environment is a background noise in the office without ventilation. Measurements were taken on a non-working day in an empty office. The average recording time was 5 minutes, with the outside noises heard from passing vehicles. The recordings were listened to and adjusted to eliminate all noise and to keep the background noise from running computers and the server. Entries were extended by stringing them together and are 10 minutes long. The purpose of the recording was to identify the quietest possible working environment.

The second type of environment is again background noise, again measured on non-working days, but with the ventilation system on, which increases the noise level by about 10dB to 15dB. This measurement is designed to present the office environment very early in the morning or late at night when some people may prefer to work.

The third environment was measured at the end of a normal workday at each of the positions. The recordings are 30 minutes long at each point. The average sound level is around 56dBA. For the purpose of the test, 10 min were selected from the recordings where the sound level is maximal and includes intelligible and incomprehensible speech as well, external noise sources, printing machines, high-level conversations and laughter.



**Figure 6.** Photo from the measurements on site-position 2.

## 7. PARTICIPANTS

All of the selected participants had been working in the same workstations for at least 3 months before the experiment and were quite familiar with the office environment. The creativity tests were done by them in the same positions where they normally work so the same light and thermal comfort of a normal work day was provided. Before starting the experiment they were familiarized with the concept of the experimental tests. Each subject filled in a questionnaire at the beginning of the tests, in order to evaluate the subjects' personal profile and their attitude towards starting the experiment. The tests were conducted sequentially by the three participants, starting with the first position. The acoustic environments for the tests were in a different order for each participant. After completing the experiment every subject was interviewed to take into consideration their personal stance towards every test and the simulated acoustic environment.

## 8. RESULTS

The purpose of the presented results is not to make comparisons between people or to determine the level of their creativity, but to see how it can be altered depending on different acoustic environments. Therefore, the results are presented as the difference score from the current test under consideration with the arithmetic mean of the three tests of each participant. These results are then averaged according to each environment.

The results of the arithmetic mean differences for each test are presented in Figures 7-9.

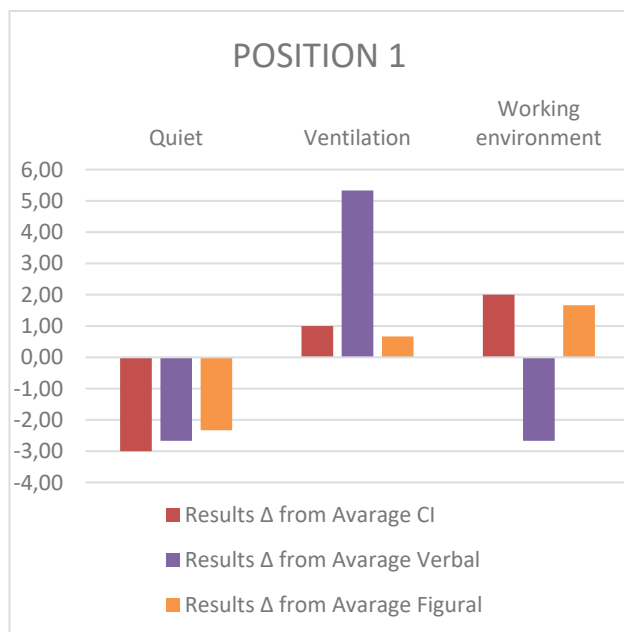


Figure 7. Test results for Position 1.

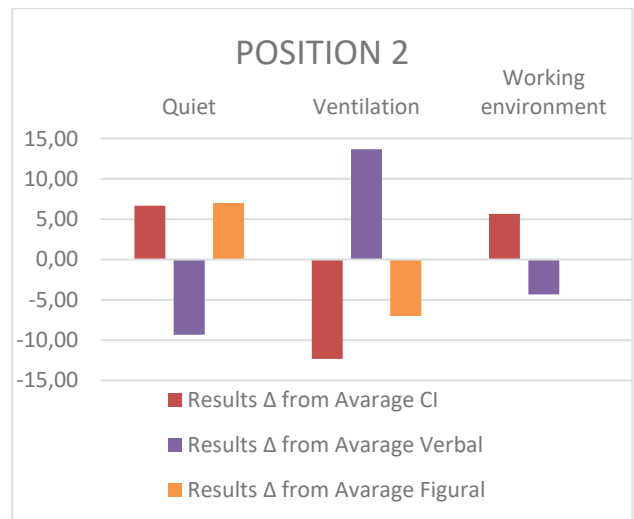


Figure 8. Test results for Position 2.

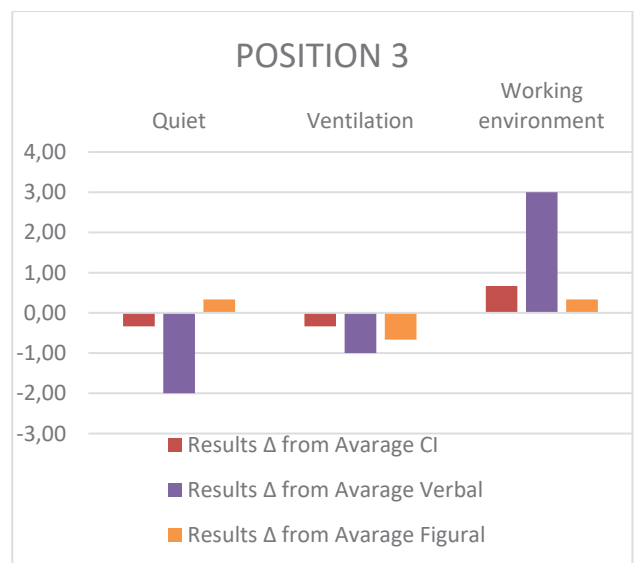


Figure 9. Test results for Position 3.

The results of the average creative parameter value for all tests are presented in Figures 10-12.

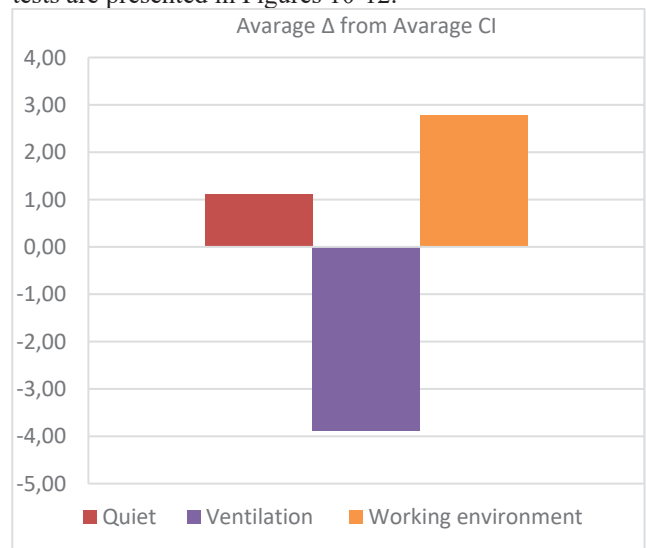
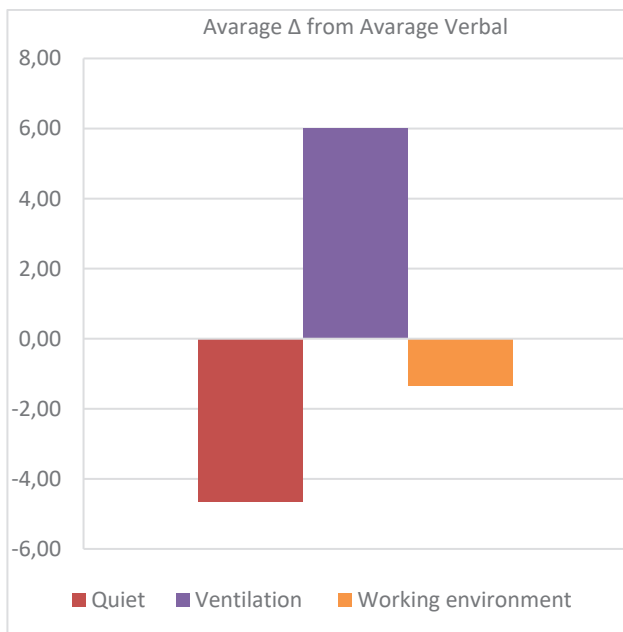
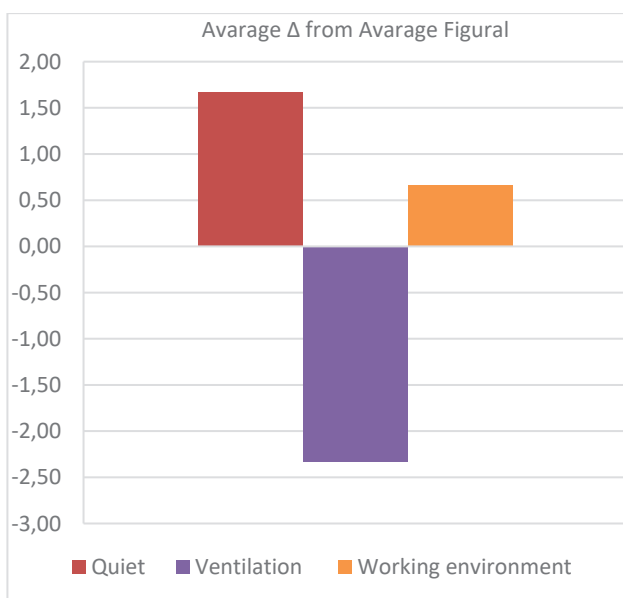


Figure 10.  $\Delta$ CI for tests in the same acoustic environment.



**Figure 11.**  $\Delta$ ASS verbal for tests in the same acoustic environment.



**Figure 12.**  $\Delta$ ASS figural for tests in the same acoustic environment.

## 9. DISCUSSION

When discussing the results of our study, we have to take into consideration the findings of Toplyn and Maguire. According to them, for highly creative individuals, a moderate noise level may lead to higher creative performance relative to both low and high noise levels. On the other hand, for less creative individuals, there is no significant difference in creativity between low, moderate and high levels of noise [15]. Following this line of thought, we can see in Figure 9 that the test results from position 3 show a little deviation, while the results from positions 1 and 2, shown in Figures 7-8 are

more explicit towards the effects of the acoustic environment on creativity.

Another interesting finding can be observed in Figures 10-12. All of the creativity parameters, that we have examined, behave differently towards the settings. In Figure 10 the  $\Delta$ CI for all participants shows that the working environment with distinctive speech intelligibility is quite beneficial for the person's creativity, while ambient sound with ventilation has exactly the opposite effect. On the other hand verbal creativity is stimulated by moderate noise with ventilation (Figure 11), while speech intelligibility is more of a distraction than a stimulus and quiet environment does not have a positive effect on verbal creativity either.

The comparison between Figures 10 and 12 presents the similarities and distinctions between ASS figural and CI. Although they are both badly affected by ventilation, ASS figural shows better results in a quiet environment unlike CI.

## 10. CONCLUSION

Open-plan offices are leading in a number of premises occupied by companies and their environment has an undisputable effect on every aspect of work tasks. When it comes to creativity and its dependency on the environment, it is affected more in highly creative people than in those with low or moderate levels of creativity. Although the number of participants was limited to only three (three creativity tests per participant), the results provide an interesting picture of how creativity works in real work environment. Contrary to the understanding that intelligible speech has an unfavorable effect on work tasks, creativity is stimulated by it. Which leads to the conclusion that work environment has to be adapted according to the nature of the work tasks, or different environments for specific purposes have to be provided.

In conclusion, we can say that the experiment has to be continued with a larger group of participants in order to prove our statements. We intend to develop it further in our next research.

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