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Exploring the potential influence of visual conditions on the acoustic perception in an office setting

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Abstract

Indoor environmental quality (IEQ) strongly influences occupants' health, comfort, and productivity. Therefore, it is essential to study the factors that determine the quality of the indoor environment, which typically pertain to the thermal, visual, acoustic, and air quality domains. In this context, efforts have been made to address possible cross-domain effects among multiple IEQ factors. However, the current state of knowledge in this area is still limited. This paper aims to expand the existing IEQ literature by focusing on the potential influence of the visual environment on acoustic perception. To this end, data collected within the framework of a recent research project is used. This project involved an empirical office-based experiment with 78 participants, and the results showed a small but significant effect of the acoustic environment on participants' visual discomfort. The present contribution examines the influence in the opposite direction, that is, whether visual conditions influence participants' acoustic perception. The results did not display an impact of visual exposure (as characterized in terms of prevailing degrees of glare) on acoustic perception (as expressed in terms of both sensation and satisfaction) for any of the three acoustic settings considered in the experiments. This suggests that cross-domain interactions may not be bidirectional.

Keywords: *acoustics, visual, indoor-environmental quality, perception, empirical study*

1. Introduction

People spend a large part of their time in indoor environments. Therefore, it is important that they are provided with a suitable indoor environmental quality (IEQ), as it directly influences their health, comfort, and productivity [1, 2]. IEQ typically involves four key domains, namely thermal, visual, acoustic and indoor air quality. In order to establish proper standards and guidelines for these environmental factors, it is essential to understand their effects on occupants. Most existing standards and guidelines are based on a single-domain approach. However, in recent years, there has been a growing number of research efforts aimed at studying cross-domain IEQ-related interactions. However, designing and conducting experimental studies that address cross-domain interaction require considerable effort and complexity. As a result, knowledge in this area is still limited and somewhat inconsistent, highlighting the need for further research, a larger number of studies, and a richer repository of experimental data to better understand how people perceive indoor-environmental conditions [3, 4, 5].

This paper aims to contribute to the cross-domain IEQ research via exploration of potential perceptually relevant interactions between the acoustic and visual exposure variables. To this end, data collected within the framework of a recent research project is used [6]. This involved an experiment with 78 participants in an office environment, where the research focus was to examine how the acoustic environment influenced participants' visual perception. Partial processing of the study's results revealed a small but statistically significant effect of the acoustic environment on visual discomfort. However, this paper aims to examine this influence in the opposite direction. Specifically, the research question is whether different visual exposure conditions influence participants' acoustic perception. As such, the present study explores the potential bi-directionality of acoustic-visual interactions between the acoustic and visual dimensions of the indoor-environmental exposure.

2. Methodology

The experimental study was conducted in an office at the Graz University of Technology (Austria). A total of 78 individuals (63% female, 37% male, aged 18 to 30 years) volunteered to participate in the study, following prior approval from the university's Ethics Committee and with written informed consent. None of the participants had any major visual or hearing impairments.

The study consisted of individual sessions in which participants spent 90 minutes at a workstation under controlled acoustic and visual conditions. Thermal and air quality variables (i.e. room temperature, humidity and CO_2 concentration) were continuously monitored. The workstation consisted of a desk with a computer screen, a keyboard, a mouse, and a luminaire situated above the computer screen at participants' field of view (see Figure 1).

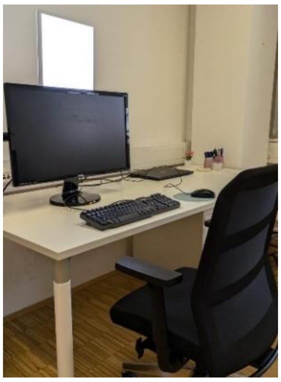

Figure 1. Workstation of the experimental study.

During the sessions, participants completed a series of tasks (e.g., reading, comprehension, answering questions), and were also asked to respond to questionnaires regarding their perception of the indoor environment at predefined time instances during the experiment. In the present paper, we focus on their acoustic perception, which was assessed in terms of acoustic sensation and satisfaction. The respective questions were *"How do you perceive the sound intensity in the room at this moment?"* (measured in a 7-points scale from *Very low* to *Very high*) and *"How satisfied are you with the acoustic environment in the room at this moment?"* (measured in a 6-points scale from *Very dissatisfied* to *Very satisfied*).
Each experimental session consisted of three phases. During each phase, one of the three acoustic conditions was applied in a randomized order across participants, while the four visual conditions were presented in randomized sequence within each phase. The structure of the experimental schedule is illustrated in Figure 2.
Participants were asked to report their acoustic perception at the end of each phase in order to avoid drawing continuous attention to the acoustic environment throughout the exposure period. For the analysis, the relevant visual condition was defined as the one presented at the moment participants provided their acoustic perception rating.
The four visual conditions corresponded to four levels of glare induced by the aforementioned luminaire. Glare levels were defined in terms of the Unified Glare Rating (UGR) [7] and measured using a calibrated camera and corresponding software [8]. The measured UGR levels were 13.1, 18.2, 23.4, and 26.7 (labeled as V1-V4, respectively).
The three acoustic conditions consisted of three different types of noise: background pink noise at an equivalent continuous sound pressure level (L_{Aeq}) of 40 dBA, office noise at an L_{Aeq} of 60 dBA, and traffic noise, also at an L_{Aeq} of 60 dBA. The pink noise condition was intended to represent

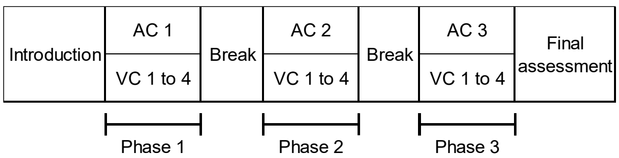

Figure 2. Schedule of one experimental session.

a quiet acoustic environment, while the other two conditions were expected to be perceived as louder. The main difference between the two higher-level conditions lies in their spectral content, whereby the traffic noise treatment involved typical vehicular and road-related sounds, whereas the office noise treatment included sounds such as printers, doors, footsteps, and speech. The sound field was generated using a set of off-sight speakers and a woofer [9].
Based on the experimental design and research question, the aim was to evaluate whether participants' acoustic perception is influenced by the visual conditions they are exposed to, and to further explore this effect across the three acoustic settings in order to assess if differences arise depending on sound level or spectral characteristics.

3. Results and discussion

Prior to the discussion of potential cross-domain effects, it is useful to consider the single-domain relationship between the acoustic exposure and its perception, independent to the specifics of the visual. The results are illustrated in Figure 3 and Figure 4 for acoustic sensation and satisfaction respectively.
As expected, pink noise was perceived as less loud and more satisfying than both office and traffic noise. Comparing the latter two conditions, acoustic sensation ratings showed similar distributions, whereas for acoustic satisfaction, the median values indicate that perception of the traffic noise was slightly more negative than the office noise.

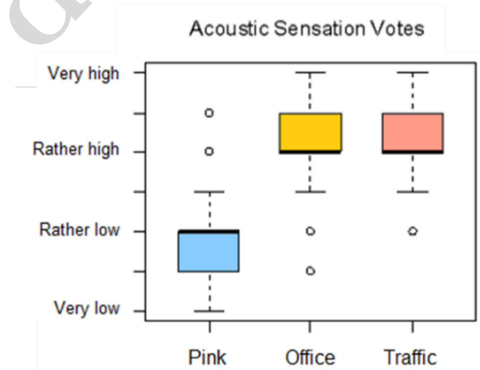

Figure 3. Acoustic sensation votes' distribution (boxplot) for each acoustic condition (Pink, Office and Traffic noise).

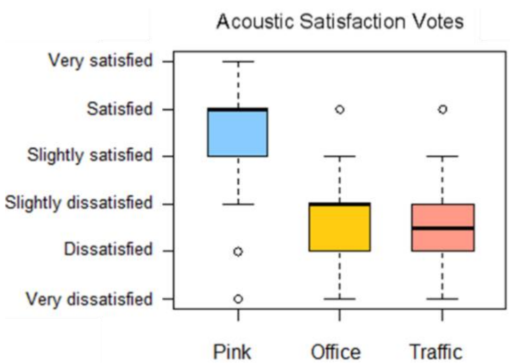

Figure 4. Acoustic satisfaction votes' distribution (boxplot) for each acoustic condition (Pink, Office and Traffic noise).

To explore potential cross-domain effects of the visual exposure on the acoustic perception, the results are presented in terms of participants' acoustic perception across the four visual conditions for the three acoustic exposures, in order. To this end Figure 5 and Figure 6 show, as boxplots, the distribution of the acoustic sensation and satisfaction votes respectively.

The distribution of acoustic sensation votes does not follow any clear pattern in any of the three acoustic environments and remains similar across the four visual conditions. This suggests the absence of discernible effect of the visual settings on the acoustic sensation.

As for the visual satisfaction, the hypothesis of a possible influence of the visual conditions on acoustic satisfaction would imply more negative rating of the acoustic conditions under higher levels of glare-induced visual strain. However, the distribution of the acoustic satisfaction votes shows no clear differences among the different visual conditions in all three acoustic environments. The median for the pink noise condition is the same across all four visual conditions. In case of traffic noise, the median is one step lower in V3 and V4 as compared to the lower visual conditions, which is in principle consistent with the aforementioned hypothesis. However, the office noise condition does not follow this pattern, as it shows the highest satisfaction ratings in both V1 and V4.

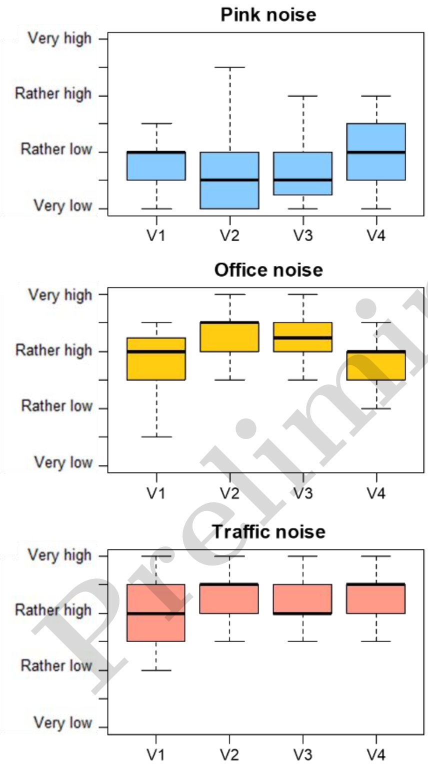

Figure 5. Distribution of acoustic sensation votes' distribution (boxplot) for each acoustic condition (Pink, Office and Traffic noise).

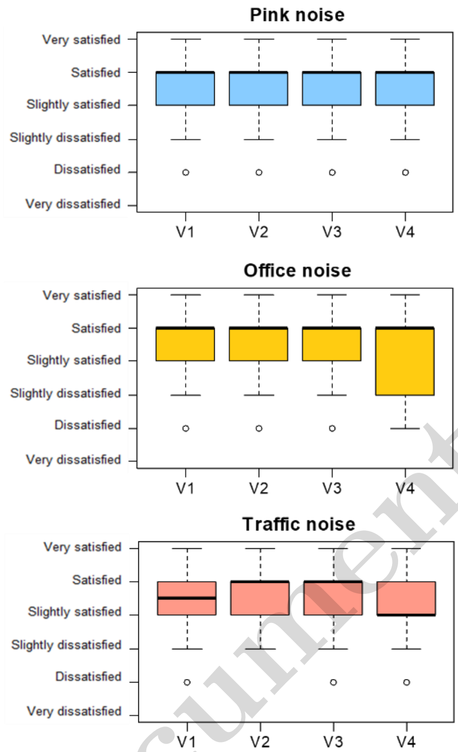

Figure 6. Distribution of acoustic satisfaction votes' distribution (boxplot) for each acoustic condition (Pink, Office and Traffic noise).

To explore this effect further, inferential statistics was applied using a cumulative link mixed model (CLMM). Based on a significance level of $p = 0.05$, the results indicate no effects in the pink noise environment (V2: Estimate = 0.164, $p = 0.826$; V3: Estimate = 0.013, $p = 0.985$; V4: Estimate = -0.968, $p = 0.149$), nor in the traffic noise environment (V2: Estimate = -0.401, $p = 0.562$; V3: Estimate = -0.633, $p = 0.369$; V4: Estimate = -0.143, $p = 0.823$). However, in case of office noise, minor effects were observed for V2 (Estimate = -1.744, $p = 0.0156$) and V3 (Estimate = -1.573, $p = 0.0306$), but not for V4 (Estimate = 0.505, $p = 0.4137$).

These results do not point to a significant influence of visual conditions on acoustic satisfaction, with the exception of the office noise treatment, where a small effect could be registered.

4. Conclusion

This study presented the findings of an experimental research focusing on the potential perceptually relevant effects of acoustic and visual interactions. A previous study based on the same experimental data examined whether the acoustic environment could influence participants' visual discomfort. That study identified a small but significant effect, with higher acoustic strain leading to increased visual dissatisfaction. The present contribution aimed to explore the potential effect in the opposite direction, that is, whether visual conditions influence participants' acoustic perception. This was explored in three different acoustic environments: pink noise at 40 dBA, and traffic and office noise, both at 60 dBA.

As expected, results show that participants rated the pink noise condition as less loud and more satisfactory compared to the other conditions. When exploring the potential influence of the visual conditions on acoustic sensation and satisfaction, descriptive statistics did not show any clear pattern of the visual settings having an influence on acoustic satisfaction. However, application of inferential statistics revealed a small but not insignificant effect for some visual conditions in the office noise setting. This suggests that the potential influence of visual conditions on acoustic perception may depend not only on sound level but also on the type of acoustic environment.

Overall, the results from the present contribution do not establish a perceptual bi-directionality in acoustic–visual interactions. Given the limitations of the present study in view of the sample size, building typology, and treatment duration, further studies are needed to arrive at conclusive insights regarding potential effects of visual circumstances on the perception of the acoustic conditions in buildings.

5. Acknowledgments

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