Improving both cognitive performance and subjective evaluations in open-plan offices by combining partial maskers

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ABSTRACT

Office noise has been shown to impair cognitive performance and subjective evaluations in a multitude of studies. To reduce such disturbance effects, continuous noise is played in many open-plan offices as a partial masker. Yet, whether another sound, such as music or nature sounds, can be used instead is questionable and could not be unequivocally answered in extant studies [1, 2, 3].

The reported experiments investigated whether the beneficial performance effects of continuous noise and the positive preference ratings of instrumental music reported by Schlittmeier and Hellbrück [3] can be unified into one partial masker by combining these two sounds.

In Experiment 1, short-term memory performance (n = 40) was tested during silence, office noise and three masking conditions in which a combined masker, continuous noise or music was superimposed on office noise. In Experiment 2, subjective evaluations were collected from students (n = 72) who did academic homework for 1 h during one of the three masking conditions of Experiment 1. In sum, performance data and subject ratings underline the potential of a composite masker (continuous noise plus instrumental music) for office environments.

INTRODUCTION

Open-plan offices are utilized for diverse reasons, e.g. lower operation costs compared to single offices, a more flexible exploitation of the available space, improved cooperation and communication among employees, or even as a symbol for certain company values. However, these desired advantages do not always occur, and often any positive effects on communication among employees in open-plan offices cannot be verified [4]. Apart from these uncertainties, one fact is absolutely certain: An occupied open-plan office is by no means silent.

Yet office noise correlates with reduced job satisfaction [e.g., 5, 6], an increase in doctor's notes [e.g., 7], and decreased physical and mental well-being [e.g., 8]. Employees subjectively perceive office noise and background speech as being disturbing [e.g., 9-13]. And besides that subjective feeling, office noise demonstrably reduces cognitive performance, especially if it consists of background speech [e.g., 14-17].

Many companies have introduced masking sound in open-plan office environments to combat the potential negative impacts of office noise. Typically, continuous broadband noise is used as a masking sound, i.e. to partially mask disturbing background sounds. Soft sounds (e.g. typing, turning pages, clattering, etc.) are drowned in the additionally played-back acoustic background and irrelevant speech is reduced in intelligibility. In particular, the latter aspect is highly appreciated since the intelligibility of speech produced by colleagues at distant work stations is considered to reduce the acoustic quality of an open-plan office (ISO 3382-3) [18]. However, the permanent playback of continuous noise is not generally appreciated by those concerned [1, 3].

Consequently, some studies explored the question of whether less artificial background sounds can be used instead of continuous noise, namely music [1, 3] or nature sounds like spring water [1] or water waves [2]. Schlittmeier and Hellbrück [3] found legato-music to be more broadly accepted by the participants as a masker of office noise than continuous noise but lacking a significant reduction of the negative performance effects evoked by office noise without maskers. In this study, only continuous noise reduced the disturbance effect of office noise as a mask but it did not perform well regarding subjective evaluations. In the studies reported by Haapakangas and co-authors [1] and Keus van de Poll et al. [2], however, continuous noise did not reduce negative performance effects of background speech. Instead, spring water sounds and water wave sounds helped to reduce negative performance effects of background speech as maskers. Yet, neither spring water [1] nor water waves [2] were rated subjectively better than continuous noise.

In sum, the extant studies so far do not speak in favour of one certain sound being used as a partial masker in office environments. Neither music nor nature sounds nor continuous noise was able to consistently provide beneficial effects on both to be optimized dimensions – objective performance measures and subjective evaluations. Thus, the present study follows another idea, namely, combining one sound which functions in auditory-perceptive perspective as a masker for office noise with an in subjective perspective appreciated sound. According to the results of Schlittmeier and Hellbrück [3], continuous broadband noise and instrumental music were chosen for this purpose. The idea was that the composite masker ("masked music") should be characterized by instrumental music being so soft that one can follow the melody if listening attentively to the composite masker, which should promote preference ratings. Yet if one concentrates on the cognitive task at hand, the music should "vanish" in the background. With this, the disturbance impact of the overall background sound (office noise plus the composite masker "masked music") should be minimized.

Experiment 1 tested the effects of such a composite masker on cognitive performance and subjectively perceived disturbance in an experimental set-up as used in the aforementioned studies [1, 2, 3].

EXPERIMENT 1

Experiment 1 explored whether the detrimental effects of office noise can be reduced if "masked music" is superimposed on it, which is a combination of continuous noise and instrumental music. Serial recall performance was chosen as the performance measure because it is the standard task for investigating the impact of irrelevant backgrounds sounds on cognitive performance [e.g., 1, 2, 3]. In addition, subjective disturbance ratings were collected, and participants were asked several questions about their preferences regarding the acoustic work environment.

Methods

40 students (24 students from the Catholic University of Eichstätt-Ingolstadt and 16 students from the University of Applied Sciences Döpfer, HSD Hochschule Döpfer) participated in the experiment. Participants (33 female) were aged between 17 and 43 years (Md = 19.5 years). They had responded to a notice and reported normal hearing. Participants received a small honorarium or credit points.

Five background sound conditions were tested: silence (no background sound presentation), office noise and three superimposed versions of office noise. The office noise was recorded in a real open-plan office using an artificial head (HRS II.2, HEAD Acoustics GmbH) and a digital audio tape (DAT; 44100 Hz sampling rate and 16-bit resolution). It primarily contained background speech (mother tongue) but also non-verbal parts (e.g., a ringing telephone, shuffling of paper, printer noise). The three superimposed versions of office noise were generated by mixing the digitally recorded office noise with one of three additional sounds with SNR = 0 dB(A): (1) continuous noise, (2) instrumental music, (3) masked music. Continuous noise was pink noise generated using the software SoundEdit 16 (Macromedia, Inc.). The piece of instrumental music was Johann Sebastian Bach's Prelude 1 in C-major (BWV 864), played on acoustic guitar. “Masked music” was generated by mixing sound conditions (1) and (2) digitally and of equal sound pressure level, i.e. signal-to-noise ratio (SNR) = 0 dB(A). This SNR was chosen according to a pretest in which 10 participants listened to different SNR combinations of music and continuous noise. An SNR of 0 dB(A) was perceived as appropriate by 7 of 10 participants to best fulfil the criterion of the music “vanishing” in the continuous noise if concentrating on a visual task at hand, but being perceptible, if listening attentively to the background sound. All background sound conditions were played back with L_{eq} = 55 dB(A), measured with a Brüel & Kjær 2231 sound pressure meter, via a Westra LAB-501 loudspeaker positioned centrally behind the participant. Sequence of sound conditions was balanced over participants.

The experiment was carried out in single sessions in a quiet experimental room at the Catholic University of Eichstätt-Ingolstadt or at the HSD, respectively. An experimental session lasted about 1.5 hours. A Macbook Pro with a 15’’ TFT-screen, driven by Psyscope XB57 experimental software [19], was used to present the serial recall task and to register participants’ responses. The experiment started with written instructions that emphasized that the background sounds were irrelevant and had to be ignored. In the serial recall task, the digits from 1 to 9 were displayed in the middle of the computer screen in randomized order one after the other (700 ms on, 300 ms off; font: Chicago, 56 pt). The beginning of the list was announced 3 s in advance by three rectangles decreasing in size in the middle of the screen. Six practice trials with silence preceded the test trials. A trial consisted of the serial presentation of the 9 digits to be remembered for the serial learning task, followed by a 10 s retention interval and recall. For recall, a 3 x 3 display of rectangles appeared, with the digits randomly rearranged from trial to trial. Participants were asked to click on the digits in the order in which they had been presented. After each click, the colour of the digit and its field inverted, and that digit could not be selected again; thus, it was not possible to correct errors.

There were 12 successive trials in each of the five sound conditions. The sequence of sound conditions was balanced over participants. The background sound was present during the entire corresponding experimental block. There was a pause of 3 min between blocks.

After completion of the serial recall task, participants were asked to rate the different sound conditions on a 5-point scale from 1 (not at all disturbing) to 5 (extremely disturbing) according to the question “How disturbing were the different sounds to you?” Furthermore, participants answered the following questions by choosing between the given alternatives (forced choice): “With respect to office work: Do you prefer to work with or without masking sound?“; “If masking sounds were to be played-back during office work — which partial masker out of music, masked music and continuous noise would you prefer?”.

Results

The serial recall task was scored using a strict serial recall criterion: One point was only assigned to an item if it was recalled in the serial position at which it was presented before. Mean error rates for each sound condition are presented in figure 1 (upper panel) together with mean ratings on subjectively perceived disturbance (lower panel).

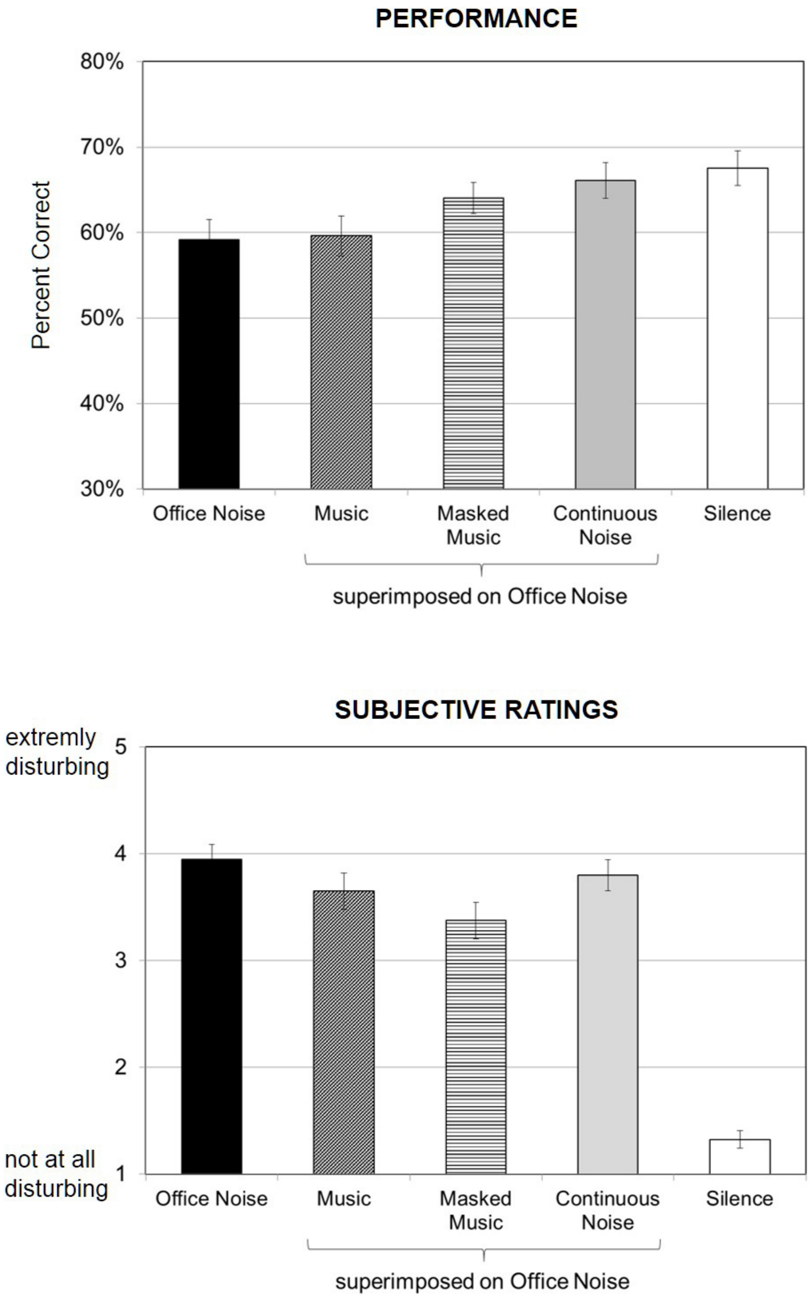

Figure 1: Working memory performance (upper panel) and subjectively perceived disturbance (lower panel) during office noise with and without maskers in Experiment 1(n = 40). Means of error rates and disturbance ratings are depicted with standard errors.

A one-way Analysis of Variance (ANOVA) was conducted on performance data, with sound condition (silence, office noise, continuous noise, music, masked music) as a within-subjects factor. The analysis verified a significant effect of sound condition, $F(4, 156) = 8.31$, $p < .001$ ($MSE = 0.057$, *partial* $\eta^2 = .18$). T-tests for dependent samples with the Benjamini-Hochberg α-error adjustment [20, 21] revealed the following sound effect pattern. Office noise significantly reduced serial recall performance in comparison to silence ($p < .01$, one-tailed, Cohen's $d = 0.61$). Its detrimental impact was not reduced by superimposition with music ($p = .43$, one-tailed), but by superimposition with continuous noise ($p < .01$, one-tailed, Cohen's $d = 0.49$) as well as by superimposition with masked music ($p < .01$, one-tailed, Cohen's $d = 0.37$). Although performance during the latter two sound conditions did not differ significantly ($p = .23$, two-tailed), performance level during office noise with masked music was significantly lower than during silence ($p = .01$, one-tailed, Cohen's $d = 0.29$), which not held true for continuous noise superimposed on office noise ($p = .21$, one-tailed).

Subjective ratings were also significantly affected by the within-subject factor sound condition, $F(4, 156) = 65.49$, $p < .001$ ($MSE = 46.70$, *partial* $\eta^2 = .63$). Consonant with performance data, office noise was perceived as being disturbing compared to silence according to t-tests for dependent samples with the Benjamini-Hochberg α-error adjustment [20, 21] ($p < .01$, one-tailed). However, the beneficial performance effects of superimposing continuous noise over office noise was not reflected in less negative subjective disturbance ratings of the masker condition ($p = 0.20$, one-tailed). On the contrary, superimposing office noise by masked music resulted in significantly lower disturbance ratings compared to office noise without masker ($p < .01$, one-tailed, Cohen's $d = 0.59$) as well as compared to office noise with continuous noise ($p < .01$, one-tailed, Cohen's $d = 0.43$). Nonetheless, masked music was rated – like office noise and all other superimposed versions of it – as significantly more disturbing than silence ($p < .01$, one-tailed).

In the post-experimental questioning, only 14 of the 24 participants mentioned that they prefer to work with masking sounds in the presence of office noise. This is surprising, since the detrimental impact of office noise on cognitive performance was significantly reduced during continuous noise as well as during masked music. Also, if additional sounds were compulsory at the office, participants expressed a greater preference for working with the accompaniment of music ($M = 3.9$, $SD = 1.2$) than with continuous noise ($M = 2.4$, $SD = 1.3$) or masked music ($M = 2.4$, $SD = 1.3$). The latter two maskers were rated highly similarly.

EXPERIMENT 2

In Experiment 1 participants were exposed to a certain background sound condition for ~10-15 min before subjectively evaluating it. A working day, however, lasts several hours, so that it is a reasonable question whether subjective evaluations vary with exposition time. Thus, Experiment 2 tested the effects of an exemplarily prolonged exposition time of 1 h on subjective evaluations of the three masked office noise conditions of Experiment 1: either masked music, only music or only continuous noise were superimposed on office noise.

Methods

Seventy-two students (51 female) from the University of Applied Sciences Döpfer (HSD Döpfer) took part in Experiment 2. They were aged between 18 and 39 years (Md = 20 years). All participants had responded to a notice and reported normal hearing. Credit points were given for participation. Participants were offered different time slots during which up to 8 participants could take part in the experiment. The three sound conditions were assigned by the author in such a way in the group testing sessions that 24 participants worked during each of the three sound conditions.

Testing took place in a lecture room of the HSD Hochschule Döpfer with 40 seats. Four seats in the second and four seats in the third row were used as workplaces. A testing session lasted about 1 h 20 min. Participants were asked to bring their own study work to the testing session, on which they could work concentrated and silently (no group discussions, no reading aloud, no tapping noises). The three masked office noise conditions from Experiment 1 were used, namely continuous noise, music or masked music superimposed on office noise, with the masked music being a combination of continuous noise and music. These sound conditions were presented via an ION Audio Block Rocker M5 loudspeaker placed on the front desk of the lecture room at L_{eq} = 48 dB(A) ± 3 dB(A) depending on the working location of the participant. Sound pressure levels were measured using an iPhone 3G and the app Soundmeter 3.3.1. (For such a measurement set-up mean differences of ±2 dB to a reference sound level measurement system have been reported by [22]).

At the beginning of the experiment, each subject got a paper-pencil questionnaire, first asking about gender, age, course and the type of cognitive task that was brought. Then 30 s pieces of the three masking sounds were played back to participants: continuous noise, music and masked music. After each short presentation, participants were asked to answer the question "How likely would you choose this sound when performing cognitive work in an open-plan office?" on a 5-point scale from 1 ("very unlikely") to 5 ("very likely"). Then each group of participants worked for 1 h under one of the three background sound conditions, i.e. office noise was played-back and accompanied by one of the three masking sounds. After this working period, during which participants were asked to work silently on the tasks they had brought with them, participants were asked to rate the present masking sound once again on the aforementioned 5-point-scale. Thus, all 72 participants rated all three sound conditions at the beginning of the experiment, but at the end of the experimental session each participant only rated the one sound condition during which he/she had worked for 1 h. (Furthermore, subjects had to elaborate the EZ-Scale and the NASA-TLX questionnaire, as well as three additional questions on subjectively perceived annoyance and disturbance impact of the background noise. The corresponding results are not reported in this paper.)

Results

Figure 2 depicts means of preference ratings on the question: "How likely would you choose this sound when performing cognitive work in an open-plan office?" Ratings collected at the beginning of the experiment after 30 s exposition time are depicted in the left panel, while ratings collected at the end of the working period are given in the right panel. Ratings were tested regarding an effect of the factor *masker* (continuous noise, music, masked music) with two one-way ANOVAs. *Masker* was a within-subjects factor for ratings after short exposition (30 s), and a between-subject factor for ratings after long exposition (1 h). In both cases, there was a significant effect of masking sound on ratings (short exposition: $F(2, 142) = 110.33$, $p < .001$ ($MSE = 84.57$, *partial* $\eta^2 = .61$); long exposition: $F(2, 69) = 27.40$, $p < .001$ ($MSE = 16.79$, *partial* $\eta^2 = .44$). The exact effect pattern, however, was completely different for short and long exposition times.

After short exposition, participants rated continuous noise to be the sound they would least likely choose as a masking sound for office noise whereas they rated music as their most likely choice. Preference ratings for masked music were between the other two sound conditions and in fact in the middle of the used 5-point scale. All comparisons between the three masking conditions were significant (t-tests for paired comparisons; $p < .001$, two-tailed).

For ratings after long exposure all comparisons were significant, too (t-tests for independent samples; $p < .01$, two-tailed). Here, however, masked music achieved the highest preference rating. It was rated as likely to be chosen as a masker followed by continuous noise and finally by music, which was now rated as unlikely to be chosen.

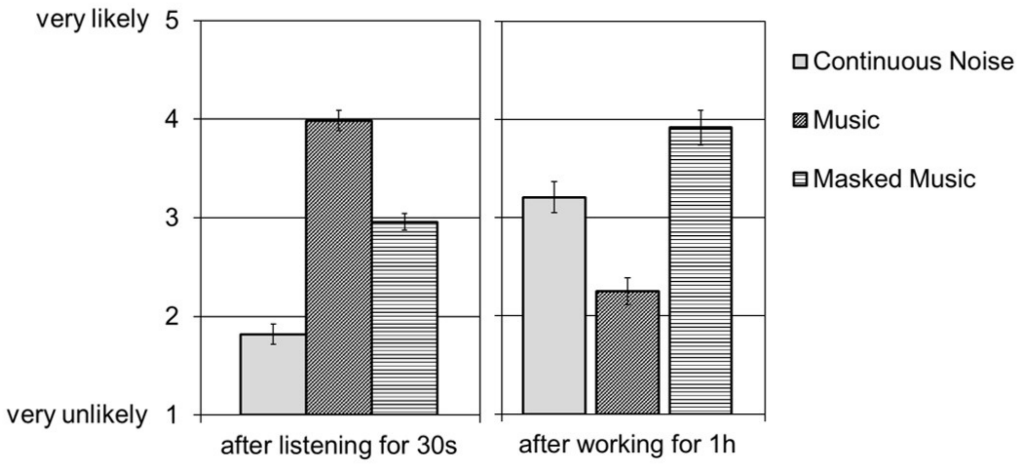

Figure 2: All participants answered the question how likely they would choose a sound as a masker for cognitive work in an open-plan office after briefly listening to all three sound conditions at the beginning of Experiment 2 (n = 72; left panel) and once again for the masker condition during which a participant had worked for one hour ($n_1 = n_2 = n_3 = 24$; right panel). Rating means with standard errors are given.

DISCUSSION

The purpose of the present study was to test the effectiveness of a composite masker in reducing the detrimental impact of office noise on cognitive performance and acoustic comfort. The composite masker “masked music” was derived by superimposing instrumental music with continuous noise. Its effects were contrasted with the effects of the ingredient masking sounds, i.e. instrumental music and continuous noise, respectively.

Experiment 1 verified that masked music reduces the detrimental effects of office noise on cognitive performance significantly, as does continuous noise, too, but not instrumental music. Furthermore, masked music was subjectively rated as significantly less disturbing than office noise without masker and as office noise superimposed by continuous noise. In Experiment 2, too, subjective preferences clearly speak in favor of the composite masker for office noise abatement. Additionally, the experiment demonstrates, that preferences change with prolonged exposition time. Whereas at first “glance”, music is rated as the most preferred masking condition, it is the least preferred masker after having worked for 1 h during it. Instead, masked music is rated as the most preferred masking condition for office noise after that prolonged time period. Since any noise abatement system must be beneficial in terms of both objective performance as well as subjective acoustic comfort, the present results speak in sum for the composite masker instead of only continuous noise to abate office noise.

The economic reason behind installing a masking system in an open-plan office is to reduce detrimental effects of office noise on performance. But why do office noise and background speech reduce cognitive performance – and why do partial maskers help? There is a long tradition in basic psychological research on the sound characteristics which are decisive for a performance decrement to occur in a given cognitive task. Most research focused on short-term memory performance, which is by default measured with the verbal serial recall task and has been used in the present Experiment 1, too [cp. also, e.g., 1, 2, 3]. The crucial factor for a short-term memory impairment to occur (a so-called Irrelevant Sound Effect, ISE; cp. [23]) is that the background sound is characterized by distinctive temporal-spectral variations which allow for the perceptual segmentation of an irrelevant sound while, at the same time successive perceptual tokens also change. Several empirical studies have demonstrated that reducing the acoustic mismatch between successive auditory-perceptive items in an irrelevant sound stream reduces the disturbance impact of this background sound. Specifically, a decrement of the impact of background speech disturbances has been found by enhancing level of continuous noise used for superimposition [24], the extent of low-pass filtering [25], or by reducing the pitch separation of successive speech tokens [26]. With this, the effectiveness of masking sounds with respect to reducing detrimental short-term memory effects relates to its potential to reduce the changing-state characteristics of background speech and also non-speech office noise.

Regarding short-term memory, changing-state features are crucial for a sound´s disturbance impact. With respect to other cognitive functions, a performance decrement jointly results from the properties of the characteristics of the sound and the task at hand [27, 28]. In the context of office environments, the problematic aspect of background speech for many tasks is its semantic content. According to an interference-by-process view [27, 28], the involuntary and automatic semantic analysis of background speech interferes with the execution of semantic processes to solve semantic-based tasks and thus reduces performance [e.g., 29, 30]. Consonant with this, background speech has been shown to impair performance in semantic based tasks like, for example, reading comprehension [e.g., 31] and writing [e.g., 32]. And furthermore, speech of reduced intelligibility has been shown to impair cognitive performance significantly less than highly intelligible background speech [33-35]. Thus, maskers in office environments are effectively abating the disturbance impact of background speech on semantic based tasks, if they reduce, as a consequence of reduced speech intelligibility, the semantic content of the overheard background speech. Consonant with this, the norm ISO 3382-3 [18] considers the intelligibility of speech produced by colleagues at distant work stations to cause “negative acoustics” with countermeasures targeting on reducing speech intelligibility to enhance the acoustic quality of open-plan offices.

In the present study, the beneficial performance effects of masked music were smaller than that of continuous noise alone. This result is most probably due to the fact that continuous noise was less loud when contributing to the “masked music” condition as when presented as a single masker since all masking sounds were presented with the same sound pressure level and instrumental music contributed to the overall level in the masked music condition, too. With this, however, continuous noise was less effective as a masker in the masked music condition for changing-state features on the one hand as well as for perceptual cues for speech segmentation, and thus speech intelligibility and semantic content on the other hand. Since pink noise, which was used in the present experiments, is not the best speech masker, future research might enhance the potential of a compiled masker by using a more efficient masking noise as one ingredient. Information on this task can be derived from the extant literature on the spectral characteristics necessary for continuous noise to function effectively as a masker [e.g., 36-38]. In fact, a compiled masker “masked music” might be specially designed as an entire unit to qualify with respect to both objective performance effects and subjective ratings. For example, the intentional shaping of the acoustical environment in open-plan offices using functional music (so-called Muzak, cf. [39]) is already being applied by several firms, but without providing empirical evidence for the promised positive effects. Furthermore, with respect to the promotion of maskers for open-plan offices, the present data notably demonstrate that just briefly listening to a masker does not allow to predict what cognitively performing during a certain masker might be like for those concerned.

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