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Level-adaptive sound masking in the open-plan office: How does it influence noise distraction, coping, and mental health?

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A B S T R A C T

In the open-plan office, intelligible speech is a major distractor, reducing cognitive performance. Sound masking emits an electronic broadband sound to increase the background sound level in a controlled manner. To date, most studies on sound masking are short-term laboratory studies that do not consider aspects of mental health. The current study aims to evaluate, using a longitudinal field study with intervention (N = 42) and control (N = 41) floors at two organizations, whether level-adaptive sound masking could reduce intelligible speech and increase mental health, while being exposed to level-adaptive sound masking for two to three months. The study consists of two subjective measurements, prior- and post-intervention, using survey questions on coping strategies, noise distraction, and ten mental health indicators (short-and long-term consequences). The increase in background noise level (at company 1 from 28.7 dB(A) to 41.9 dB(A) and at company 2 from 32.4 dB(A) to 42.6 dB(A)) at both organizations significantly reduced intelligible speech distraction. Short-term mental health aspects were rated more positively, and level-adaptive sound masking also reduced the frequency with which people put on radio or headphones to cope with noise.

1. Introduction

The modern workplace, often characterized by a vibrant atmosphere [12], has witnessed an increasing concern regarding the potential adverse effect of noise on employees' mental health [3]. Especially in the open-plan office, noise is the single-most important reason for performance-and comfort deficiencies [36]. Highly variable sounds, such as intelligible speech, are more distractive than steady-state sounds as they are harder to get accustomed to or to ignore [41]. As Hardy [22] already showed in the 1950 s, individuals become accustomed to a steady low frequency noise, which has the potential to mask out variable sounds. However, intelligible speech (i.e., background speech that is not useful for task performance) has detrimental effects on individuals' cognitive performance and well-being. These adverse effects can be mitigated by enhancing the acoustic design of the open-plan office through reducing the intelligibility of background speech [18].

Speech intelligibility can be measured by the Speech Transmission Index (STI), with values ranging between 0 (no intelligibility) and 1 (perfect intelligibility). Several laboratory studies explored the influence of speech intelligibility on cognitive performance and noise distraction. For example, Haapakangas et al. [19] show that speech intelligibility has a major effect on short-term memory tasks. STI values above 0.50 are generally found to be detrimental for employees' performance on these short-term memory tasks. Moreover, individuals who work within the radius of distraction of a particular person may be more distracted by its speech than people outside the radius [45]. In a well-designed acoustic office, STI can be reduced by simultaneously using room absorption materials, sufficient distance between workstations, high partitions between workstations, and an adequate level of sound masking [39].

A sound masking system emits an electronic broadband sound to increase the background noise in a controlled manner using loudspeakers, which may reduce speech intelligibility and noise annoyance. So far, most studies that explored the influence of sound masking in an open-plan office have focused on the noise level or the spectrum of the masking sound [29]. Regarding the noise level, it is found that a higher background sound level due to sound masking is associated with reduced noise disturbance and speech intelligibility. Nevertheless, the background sound level should not exceed 45 dB, as this may cause annoyance [18]. Regarding the spectrum of the masking sound, research shows that sounds with low and medium frequencies are most satisfactory, with a slope of −7 and −9dB per octave increment [25]. Previous studies thus provide evidence of how to design an effective

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masking system to reduce speech intelligibility, noise distraction, and improve cognitive performance [29].

Previous studies were however predominantly performed under controlled laboratory conditions [7,21], often featuring limited sample sizes [7,24]. Field studies where the effects of sound masking on office occupants are explored are rather scarce. Even less abundant are field studies that investigate the influence of sound masking on psychological indicators. Hongisto [24] performed a pilot study and provided suggestive evidence of reduced stress, fewer coping strategies needed, and improved self-rated work efficiency under masking conditions (A-weighted SPL of speech at 4 m of 51 dB(A), background noise level of 44 dB(A), and distraction distance of 6.2 m). Lenne et al. [29] performed a longitudinal field experiment to gain insights in the effectiveness of a sound masking system (mean ambient noise level of 53.7 dB(A), background noise level of 41.2 dB(A), spectrum with slope of −5dB per octave) on perceived fatigue, noise annoyance, noise satisfaction, and mental workload. However, they did not find significant improvements in these psychological indicators.

Therefore, this study does not only aim to explore the potential of a level-adaptive sound masking system to reduce noise disturbance and speech intelligibility, but also to improve employees' mental health. This study considers a holistic mental health approach, consisting of both positive and negative, and more short-term transient and long-term chronic aspects of mental health (following [4]. In addition, it distinguishes itself from previous studies by using a longitudinal field approach, encompassing both intervention and control floors, which makes this study unique in its sort.

Another contribution of this study is to explore whether the frequency of using coping strategies changes under level-adaptive sound masking conditions. To the best of the authors' knowledge, only Hongisto [24] provided some evidence of a reduction in coping strategies used in a small open-plan office with sound masking. Coping mechanisms may be an effective way to reduce noise disturbance and improve cognitive performance as well [33]. In general, two coping strategies can be distinguished, namely avoidance coping and approach or vigilant coping. Avoidance strategies ignore the stress or threat by trying to deny or repress it [17] and are directed away from the stressor [37]. Conversely, approach or vigilant coping focusses on the source of the threat or stress to control it [17], and is directed towards the stressor to manage the emotion or pain that results from it [37]. While avoidance strategies may yield transient benefits, vigilant coping strategies are recommended in the long-term [17]. Individuals who use avoidance strategies may experience increased disturbance over a prolonged period [16]. Notably, allocating additional effort to a task (an avoidance strategy) may deplete cognitive resources available to finish the task [26,42], possibly resulting in negative mental health outcomes, such as stress, fatigue, and reduced concentration and productivity [11,15,20]. Overall, this study explores the potential of level-adaptive sound masking to reduce noise disturbance and speech intelligibility, improve employees' mental health, and investigate possible changes in the frequency and type of coping strategies used.

2. Materials and methods

2.1. Offices

This study was performed at two organizations, one operating in the tech sector, and one in the commercial real estate services sector. At the first organization (a tech company), two intervention floors and two control floors were selected within a multi-story building with a surface area of around 1000 m^2 per floor. The number of desks per floor ranged from 52 to 70, offering in total 250 desks. The desks were separated by sound-absorbing screens of 125 cm from the floor, which were clustered in groups of six or eight. Both the intervention and control floors had a suspended ceiling. At the second organization (a real estate services company), three floors were selected within a multi-story building. Two highly similar control floors were selected and one intervention floor, with a surface area of 4020.5 m^2. The desks were separated by screens of 117 cm from the floor (35 cm from the desk height). They were evenly distributed over the floors with a maximum of 24 desks per office corner, in clusters of two desks. The total number of desks equals 120. Both the intervention and control floors had a suspended ceiling.

2.2. Participants

At both companies, respondents were not informed about the forthcoming experiment. They received information letters to explain that their "office floor has been selected for an experiment on indoor environmental quality" and that they "will be asked to take a few surveys". At the first company, information letters and surveys were sent via email by floor managers who are responsible for the communication regarding general office-floor updates or interventions. At the second company, team leaders were asked to send the information to their work teams. The direct contact between (floor) managers and their colleagues may have motivated employees to participate in the surveys, resulting in acceptable response rates. The installation of the level-adaptive sound masking systems took place during the evening hours and in the weekends in the absence of the employees.

In total, the selected office floors offer a workspace to 370 employees (See Table 1). At company 1, the first survey was filled in by 127 respondents and the second survey by 91 respondents. Only 47 employees filled in both the first and the second survey. These responses were linked through a personal, anonymous code. At company 2, 222 employees received the surveys. Of these employees, 87 responded to the first survey and 85 to the second survey. In total, 36 responses of the first and second survey could be matched for the second company. This means that 83 employees at both companies responded to the first and second survey, of which 42 worked at the intervention floor and 41 at the control floor.

2.3. Level-adaptive sound masking system

The level-adaptive sound masking equipment was installed by a renowned masking system manufacturer. The manufacturer designed the masking layout for both organizations. Another independent organization performed the acoustic measurements when the offices were empty. The manufacturer did not intervene in any way during the experiment, except for the installation of the system, which was done in the evenings and weekends. The authors emphasize that no promises regarding the results of the experiment were made to the manufacturer. At both companies, the floorplan was divided in several zones which were based on the desk layout and main activity. The sound field created by the masking system in the office was diffuse due to well-distributed loudspeakers per office zone that were installed between the false ceiling and the concrete slab. The system is equipped with adaptive volume control (AVC), which means that the sound masking level per zone is automatically adjusted to the amount of speech at the time (i.e., lower sound masking level during lower activity), within a bandwidth of 35–42 dB(A) at organization 1 and 38–43 dB(A) at organization 2.

The adaptive volume control is characterized by ceiling-mounted noise sensors and an advanced signal-processing technology to

Table 1
Number of desks, number of responses to survey 1 and 2.

	Nr. desks	Survey 1	Survey 2	Match
Company 1	250	127	91	47
		50.8 %	36.4 %	18.8 %
Company 2	120	87	85	36
		72.5 %	70.8 %	30.0 %
Company 1 and 2	370	214	176	83
		57.8 %	47.6 %	22.4 %

automatically adjust the sound masking volume according to the varying sound level. Auto volume adjustments are virtually unnoticeable and occur only for sustained variations in office noise levels and not for short periods of change. Every 15 s, the active system adjusts the sound level. The algorithm measures the peak noise level during this period ($L10\%$) and compares it to the background sound level (L95%). A small difference between these values indicates a rather quiet environment, resulting in the algorithm reducing the gain slightly (by 0.5 dB steps). A large difference indicates more activity in the environment, which results in the algorithm increasing the sound masking gain too. As a result, the overall background sound level is increased (i.e., consisting of natural background sound and sound masking). The increase in background sound level reduces the gap between the peaks and the background sound level, and therefore the masking noise stops. For instance, if the controller requests an AVC gain of 3 dB and the up-rate level is set to 0.05 dB/s, the sound masking system needs 60 s to increase by 3 dB.

The level-adaptive masking system at both organizations had a centralized architecture, consisting of a central control system and power adaptors to which all loudspeakers and microphones were connected. At the first organization, test floors were equipped with 6 microphones and 30 loudspeakers, which were positioned above the suspended ceiling. The loudspeakers were distributed across the office, with an approximate distance of 4 to 5 m. Dummy sensors (i.e., microphones) were installed at the control floors with only a visual function. At the second organization, 7 microphones and 41 loudspeakers were installed above the suspended ceiling of one larger test floor, with a speaker-distance of 4 to 5 m. When the masking system was deployed, a ramp up period of ten days was used to gradually increase the masking level to avoid a sudden major increase in background sound.

2.4. Acoustic measurements

The acoustic performance of the offices was determined according to the standard NEN-EN-ISO 3382–3-2012. Table 2 shows the experimental conditions at both organizations. For company 1, two different measurements were performed: one perpendicular to the acoustic screens between desks (i.e., with acoustic screens) and one parallel to the screens (i.e., without screens). This was done to compare effects for workspaces across each other (separated by an acoustic screen) and workspaces next to each other (not separated by an acoustic screen). In practice, the adaptive noise masking system works with Adaptive Volume Control (AVC) with a lower limit boundary of 35 dB(A) and an upper limit boundary of 42 dB(A) for organization 1, and a lower limit boundary of 38 dB(A) and an upper limit boundary of 43 dB(A) for organization 2. This means that the produced sound level by the adaptive sound masking system ranges between 35 dB(A) and 42 dB(A) for the first organization and between 38 dB(A) and 43 dB(A) for the second organization. The higher lower and upper limit boundary levels of the second organization can be explained by higher background sound levels and more telephone activities than at the first organization. To measure the bandwidth of the effects, the measurements took place for the lowest and upper volume level. Five measurement points across the office floor were used for each measurement condition. In Table 2 the average measurement results are summarized.

Table 2
Measurement results of the different adaptive sound masking (ASM) conditions at two companies, with A-weighted level of speech at 4 m distance ($L_{p,A,S,4m}$), background sound level ($L_{p,A,B}$), and the spatial decay rate of A-weighted speech level ($D_{2,s}$).

Experimental condition	$L_{p,A,B}$	$L_{p,A,S,4m}$	$D_{2,S}$
	dB(A)	dB(A)	s
Company 1: measured across screens (with screens)			
1. ASM Off	28.7	48.7	5.2
2. ASM Lower boundary (35 dB)	35.7	48.7	5.2
3. ASM Upper boundary (42 dB)	41.9	48.7	5.2
Company 1: measured in parallel to screens (without screens)			
1. ASM Off	28.7	49.7	5.0
2. ASM Lower boundary (35 dB)	36.2	49.7	5.0
3. ASM Upper boundary (42 dB)	42.3	49.7	5.0
Company 2			
1. ASM Off	32.4	49.3	4.9
2. ASM Lower boundary (38 dB)	38.6	49.3	4.9
3. ASM Upper boundary (43 dB)	42.6	49.3	4.9

2.5. Questionnaires

Table 3 provides an overview of all the variables that were included in the surveys. The following demographic variables were asked; age, gender, work hours, whether people frequently wore a headphone, and whether there were sufficient concentration spots and phone booths available. For personality, the 10-item Big Five Inventory was used [35]. Noise sensitivity was measured by the GABO questionnaire [34]. The survey also included the frequency with which people performed work tasks, used several coping strategies, and how often they were disturbed by noise. Furthermore, the Distraction Scale by Lee and Brand [28] was used to measure distraction. Last, several mental health indicators were included, which represent a range of short-term to more chronic conditions, and positive and negative mental health states. For example, for stress two items (i.e., feeling nervous, anxious, or on edge; not being able to stop or control worrying) of the PHQ-4 [27] were combined with two items (i.e., feeling stressed; ruminating/ agonizing over things) of the Stress and Worry scale by Beute and de Kort [6].

Table 3 also shows Cronbach's Alpha scores as an indicator of internal consistency of the multi-item scales. The score should range between 0.7 and 0.9 for high internal consistency. Except for sleep quality (too low) and fatigue (too high), all indicators had Cronbach's Alpha scores within this range. Inter-item correlations are calculated for scales with only two items and should range between 0.2 and 0.4. Since each personality type was measured by two items, inter-item correlations were calculated (see Table 4). Inter-item correlations were also measured for the variables depressive symptoms and job performance, because they were measured by two items only. The inter-item correlation of the personality type openness is rather low and is therefore not considered in further analyses.

2.6. Procedure

The experiment was performed between September 2022 and March 2023. First, employees at both floors were asked to fill in a pre-survey. During this phase, the sound masking equipment was installed at the intervention floors. At organization 1, this phase lasted approximately five weeks, due to the Christmas break in between. At organization 2, this phase took three weeks to complete. In the second phase, the appropriate sound masking level was reached after a ramp-up period of 10 days. During phase 3, participants of organization 1 were exposed to the masking sound at the intervention floors for 10 weeks, and of organization 2 for 13 weeks. At the second organization, the Christmas break fell within the third phase of the experiment. In the last period of the experiment, employees were asked to fill in a post survey, consisting of the same questions as the baseline survey, except for the personal, constant variables (e.g., age and gender). At organization 1, the post survey was open for four weeks, at organization 2 for eight weeks. During phase 4, the masking system was still active (see Table 5 for an overview). Both at the intervention and control floors, employees were asked to fill in two surveys, namely the pre-and post-survey even if they were not exposed to the intervention.

2.7. Statistical methods

First, bivariate analyses were performed to observe significant relationships between the independent variable and dependent variables. Because these analyses do not control for other variables on which the

Table 3
Subjective measures of personal characteristics, coping strategies, noise disturbance and distraction, and mental health variables, including Cronbach's alpha values.

Variable	Sources	Number of items	Measurement scale	Reference	Cronbach's Alpha
Personal characteristics					
Age	–	1	–	–	–
Gender	–	3	Male/ female/ other	–	–
Personality	10-item Big Five Inventory (BFI)	10	1. Strongly disagree – 5. Strongly agree	Rammstedt and John [35]	–
Workhours	–	1	–	–	–
Sensitivity to noise	GABO Questionnaire	4	1. Not sensitive – 5. Sensitive	Pierrette et al. [34]	0.86
I frequently wear headphones	–	1	Yes/ no	–	–
There are sufficient concentration spots	–	1	Yes/ no	–	–
There are sufficient phone booths	–	1	Yes/ no	–	–
Intervention or control floor	–	2	Intervention/ control floor	–	–
Work tasks	–	8	1. Never – 5. Almost every day	Budie et al. [9]	–
Coping strategies	–	10	1. None of the time – 5. All of the time	Kaarlela-Tuomaala et al. [26]	–
Distraction	Distraction Scale	5	1. Low – 5. High distraction	Lee and Brand [28]	0.78
Noise disturbance	–	6	1. None of the time – 5. All of the time	Appel-Meulenbroek et al. [1]	–
Mental health variables					
Well-being	Health at Work Survey of WHO	1	1. Low – 10. High well-being	WHO [43]	–
Productivity	Health at Work Survey of WHO	1	1. Low – 10. High productivity	WHO [43]	–
Job performance	Health at Work Survey of WHO	2	1. Low – 4. High performance	WHO [43]	–
Stress	Stress and Worry Four-item Patient and Health Questionnaire for Depression and Anxiety (PHQ-4)	4	(1. Low – 4. High stress)	Beute and de Kort [6] Kroenke et al. [27]	0.88
Depressive symptoms	PHQ-4	2	1. Low – 4. High depressive symptoms	Kroenke et al. [27]	–
Disengagement	Oldenburg Burnout Inventory (OLBI)	8	1. Low – 4. High disengagement	Demerouti and Bakker [14]	0.85
Exhaustion	OLBI	8	1. Low – 4. High exhaustion	Demerouti and Bakker [14]	0.82
Concentration	Checklist Individual Strength (CIS)	5	1. Low – 7. High concentration	Beurskens et al. [5]	0.75
Fatigue	CIS	8	1. Low – 7. High fatigue	Beurskens et al. [5]	0.92
Sleep quality	Single-item sleep quality scale (PSQ) Health at Work Survey of WHO	1	1.Very bad – 4. Very good	Snyder et al. [40]	-
		4	1. Low – 5. High sleep quality	WHO [43]	0.60
Hedonic tone	UWIST Mood Adjective Checklist	4	1. Negative – 4. Positive mood	Matthews, Jones, and Chamberlain [31]	0.77
Tense arousal	UWIST	4	1. Negative – 4. Positive mood	Matthews, Jones, and Chamberlain [31]	0.78

Table 4
Inter-item correlations for subjective measures with two scale-items.

Personality	Inter-item correlation
Agreeableness	0.23
Neuroticism	0.36
Openness	0.16
Conscientiousness	0.38
Extraversion	0.44
Mental health	
Depressive symptoms	0.25
Job performance	0.33

intervention and control group could differ, the results are inconclusive. Therefore, a Seemingly Unrelated Regression Analysis (SUR) was performed. This is a statistical technique to estimate a system of regression equations where the error terms of the dependent variables may be correlated. In this study, the error terms were expected to be correlated because the dependent variables of the model concerned variables of the same individuals. SUR can be used to estimate the relationships between multiple independent and dependent variables simultaneously. It allows for an accurate estimation of the joint behaviour of multiple dependent variables and underlying relationships and may improve the estimation results of the regression coefficients [38].

In this analysis, the post survey results of mental health, coping strategies, and noise disturbance were considered as dependent variables (Y_{post}), and the pre survey results of the same variables as well as the personal characteristics (i.e., gender, age, workhours, noise sensitivity, personality, work tasks) as independent variables (X_{pre}). The independent variables as measured in the pre-survey were used to control for possible differences between the intervention and control floor samples (Y_{pre}). Whether participants worked at the intervention or control floor was also included as an independent variable (=1, if intervention floor and = 0, if control floor) (*Test*). In this way, the estimated value of the coefficient of the binary variable represents the effect of sound masking on participants' mental health, coping

Table 5
Experimental timetable.

Phase	Masking system	Measures	Start	End	Start week	End
			Organization 1		*Organization 2*	
1	Off	Pre survey	49 (2022)	1 (2023)	38 (2022)	40 (2022)
2	Ramp-up period	–	2 (2023)	4 (2023)	40 (2022)	42 (2022)
3	On	–	4 (2023)	13 (2023)	42 (2022)	4 (2023)
4	On	Post survey	10 (2023)	13 (2023)	48 (2022)	4 (2023)

strategies, or experience of noise disturbance Eq. (1).

$$Y_{post} = b_1 * Y_{pre} + b_2 * Test + \sum_{k=1} b_{k+2} * X_{pre,k} \tag{1}$$

3. Results

3.1. Sample characteristics

The descriptive statistics of the personal characteristics (N = 83) as measured in the pre-survey are shown in Table 6. More than 70 % of the sample consisted of male respondents, with a mean age of 36 (SD = 9.3) and working almost fulltime (M = 38.7, SD = 3.3). The results of the paired sample *t*-test show a significant difference in the mean number of working hours between the intervention and control floor, indicating that people working at the control floor work on average more hours than people at the intervention floor. On average, people rated their personality as agreeable (M = 3.9, SD = 0.7), followed by conscientious (M = 3.8, SD = 0.7) and extraverted (M = 3.8, SD = 0.8). No significant differences were found between people working at the intervention and control floor. People were also somewhat sensitive to noise, but no significant differences were found between the intervention and control floor.

Table 7 shows a significant difference for the sufficiency of concentration spots at the intervention floor. Significantly less people at the intervention floor indicated that there were sufficient concentration spots in the post survey compared to the pre survey. For the control group, no significant difference between the pre and post survey is found, which seems to indicate that the intervention (i.e., sound masking) influenced the experience of the sufficiency of concentration spots at the office. Another significant difference is found for the frequency with which people had telephone conversations between the pre and post survey at the control floor. It shows that employees had significantly fewer telephone conversations in the post survey than in the pre survey. This difference has not been observed at the intervention floor.

Table 8 shows that there are some significant differences between the pre and post survey for noise disturbance but not for coping strategies. Regarding noise disturbance, it can be observed that people working at the control floor indicated significantly more disturbance by intelligible speech in the post survey compared to the pre survey. This finding cannot be observed at the intervention floor. Two significant differences are found between the pre and post survey for the intervention floor. At the intervention floor, people were significantly more disturbed by people passing by and less disturbed by noise from outside in the post

Table 7
Descriptive statistics wearing headphones, concentration spots, phone booths and work tasks.

	Intervention floor (N = 42) Control floor (N = 41)	Pre survey	Post survey	*t*-test	p-value
I frequently wear headphones	Intervention	59.5 %	57.1 %	−0.33	0.74
	Control	73.2 %	65.9 %	−1.36	0.18
There are sufficient concentration spots	Intervention	26.2 %	9.5 %	**−2.47**	**0.018**
	Control	24.4 %	29.3 %	0.70	0.49
There are sufficient phone booths	Intervention	21.4 %	19.0 %	−0.37	0.71
	Control	29.3 %	26.8 %	−0.44	0.66
Work tasks					
Individual focussed work	Intervention	4.34	4.32	−0.13	0.90
	Control	4.35	4.28	−0.52	0.61
Planned meetings	Intervention	4.19	3.95	−1.74	0.090
	Control	3.83	3.87	0.30	0.77
Telephone conversations	Intervention	3.71	3.57	−0.95	0.35
	Control	3.80	3.31	**−3.06**	**0.004**
Individual routine tasks	Intervention	3.68	3.85	1.17	0.25
	Control	3.75	3.92	1.13	0.27
Informal unplanned meetings	Intervention	3.49	3.57	0.72	0.47
	Control	3.52	3.26	−1.64	0.11
Reading	Intervention	3.10	3.32	1.13	0.27
	Control	3.35	3.01	−2.03	0.049
Relaxing	Intervention	3.03	3.11	0.45	0.66
	Control	3.30	3.43	1.02	0.31
Collaborating on focussed work	Intervention	3.07	3.32	1.40	0.17
	Control	3.17	3.01	−0.83	0.41

Table 6
Descriptive statistics personal characteristics.

	Intervention floor (N = 42)				Control floor (N = 41)				*t*-test	p-value
	Sample (N)	Sample (%)	Mean	SD	Sample (N)	Sample (%)	Mean	SD		
Gender									1.03	0.31
Male	32	76.2			14	34.1				
Female	10	23.8			27	65.9				
Other	0	0.0			0	0.0				
Age			38.0	10.0			34.2	8.3	−1.90	0.061
Personality										
Agreeableness			3.9	0.6			3.8	0.8	−1.17	0.25
Conscientiousness			3.8	0.6			3.9	0.7	0.42	0.68
Extraversion			3.9	0.7			3.8	0.8	-0.36	0.72
Neuroticism			2.4	0.7			2.4	0.8	0.52	0.61
Work hours			38.0	4.1			39.4	1.8	**2.12**	**0.038**
Noise sensitivity			3.7	0.6			3.6	0.9	−0.27	0.79

Table 8
Descriptive statistics disturbance and coping strategies.

	Intervention floor (N = 42) Control floor (N = 41)	Pre survey	Post survey	*t*-test	p-value
Distraction	Intervention	3.31	3.35	0.40	0.69
	Control	3.33	3.27	−0.64	0.53
Noise disturbance					
Intelligible speech	Intervention	3.64	3.60	−0.47	0.64
	Control	3.56	3.82	**2.47**	**0.018**
Intelligible speech from telephone conversations	Intervention	3.55	3.60	0.40	0.69
	Control	3.51	3.45	−0.38	0.71
Unintelligible background conversations	Intervention	2.79	2.98	1.14	0.26
	Control	3.07	3.07	0.003	0.99
Printers, fax, ventilation	Intervention	1.52	1.81	1.78	0.083
	Control	1.78	1.92	0.88	0.38
People passing by	Intervention	2.48	2.90	**2.74**	**0.009**
	Control	2.68	2.80	0.90	0.37
Noise from outside	Intervention	1.93	1.64	**−2.22**	**0.032**
	Control	2.07	2.12	0.29	0.78
Coping strategies					
Discussed noise problem with colleagues	Intervention	1.98	2.21	1.82	0.077
	Control	2.44	2.67	1.69	0.099
Made an even greater effort	Intervention	2.76	3.02	1.56	0.13
	Control	3.00	2.85	−0.94	0.35
Put work off till another time or overworked	Intervention	2.44	2.60	1.27	0.21
	Control	2.60	2.60	0.012	0.99
Done work more slowly than usual	Intervention	3.05	3.27	1.89	0.066
	Control	3.00	2.90	−0.88	0.39
Put on radio or earphones	Intervention	2.93	2.84	−0.77	0.45
	Control	3.15	3.44	1.50	0.14
Interrupted work of left desk	Intervention	2.59	2.56	−0.26	0.80
	Control	2.72	2.85	0.80	0.43
Tried to be quieter in the hope others would be too	Intervention	2.03	2.21	1.37	0.18
	Control	2.37	2.57	1.05	0.30
Done work more quickly than usual	Intervention	1.69	1.90	1.93	0.060
	Control	2.17	2.02	−1.18	0.25
Changed workstation or done work at home	Intervention	2.59	2.82	1.41	0.17
	Control	2.62	2.73	0.62	0.54
Made proposal to management to improve acoustics	Intervention	1.15	1.18	0.43	0.67
	Control	1.20	1.32	1.11	0.27

survey than in the pre survey. The fact that they do not occur in the control group indicate that these differences may possibly be caused by the intervention.

Last, Table 9 shows a significant difference at the intervention floor between the pre and post survey for overall sleep quality. This indicates that people's overall sleep quality was rather higher in the post survey than in the pre survey.

Table 9
Descriptive statistics mental health.

	Intervention floor (N = 42) Control floor (N = 41)	Pre survey	Post survey	t	p-value
Mental health					
Well-being	Intervention	6.79	7.19	1.60	0.12
	Control	6.55	6.73	0.87	0.39
Productivity	Intervention	7.12	7.10	−0.13	0.90
	Control	6.90	7.16	1.51	0.14
Fatigue	Intervention	3.19	3.29	0.72	0.48
	Control	3.70	3.48	−1.47	0.15
Concentration	Intervention	4.38	4.23	−1.06	0.29
	Control	4.18	4.44	1.53	0.13
Stress	Intervention	1.67	1.68	0.19	0.85
	Control	1.80	1.91	1.30	0.20
Depressive symptoms	Intervention	1.34	1.46	1.52	0.14
	Control	1.54	1.61	0.82	0.42
Tense arousal	Intervention	2.91	3.00	1.29	0.21
	Control	2.73	2.73	−0.077	0.94
Hedonic tone	Intervention	3.27	3.23	−0.47	0.64
	Control	3.02	3.14	1.63	0.11
Exhaustion	Intervention	2.18	2.20	0.49	0.63
	Control	2.28	2.26	−0.29	0.77
Disengagement	Intervention	2.03	2.14	1.92	0.076
	Control	2.37	2.44	1.64	0.11
Sleep quality	Intervention	3.90	3.88	−0.23	0.82
	Control	3.75	3.88	1.48	0.15
Overall sleep quality	Intervention	2.75	2.98	**2.43**	**0.020**
	Control	2.89	3.05	1.58	0.12
Job performance	Intervention	3.31	3.28	−0.42	0.67
	Control	3.20	3.15	−0.63	0.53

3.2. Seemingly unrelated regression analysis

The findings of the bivariate analyses showed the potential influence of sound masking on the relationships between independent and dependent variables before and after the intervention. However, these findings are inconclusive, as these one-on-one analyses did not control for other variables on which the intervention and control group could differ. Therefore, as explained in the method section, a Seemingly Unrelated Regression (SUR) analysis has been performed (see Tables 10.1 to 10.3). The adjusted R-squared of SUR indicates the proportion of explained variance by the model. Together, the independent variables explain between 16 and 65 % of the total variance of employees' mental health, coping strategies, or noise distractions. The McElroy R-squared indicates the overall best model fit according to Buse [10] and equals 0.51. This number indicates that, overall, the model fits the data sufficiently.

The SUR shows that sound masking has an influence on people's tense arousal and stress, indicating that they felt less tense/nervous and stressed with sound masking. It also reduced the frequency with which people put on the radio or headphones to cope with noise, and it decreased their perceived disturbance by intelligible speech conversations.

Regardless of the study group (intervention or control), those indicating higher disturbance by intelligible speech in the pre survey had a lower perceived productivity and well-being in the post survey. Moreover, those who were disturbed by intelligible speech at the time of the pre-survey were more likely to cope with noise by putting on the radio or their headphones at the time of the post survey, regardless of being in the intervention or control group. In addition, workers who rated high distraction levels in the pre survey more frequently discussed the noise problem with colleagues in the post survey. Employees who were disturbed by noise from outside in the pre survey felt more engaged in the post survey, again regardless of being exposed to sound masking or not. This finding is unexpected, although some individuals may find the

Table 10.1
Seemingly Unrelated Regression Analysis (1/3).

	Concentration		Fatigue		Productivity		Performance		Exhaustion		Tense arousal	
	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.
Intercept	6.06***	<0.001	1.51	0.13	4.76***	<0.001	7.13***	<0.001	6.73***	<0.001	4.38***	<0.001
Intervention floor (yes/ no)											3.17**	0.0022
Personal characteristics												
Concentration spots									−4.06***	<0.001		
Headphones	2.50*	0.014							−3.92***	<0.001		
Personality												
Neuroticism											−3.20**	0.0020
Work tasks												
Individual focussed work					2.70**	0.0086						
Planned meetings			2.76**	0.0073								
Telephone conversations			−2.59*	0.011								
Informal unplanned meetings	−3.25**	0.0017			−3.36**	0.0012						
Collaborating on focussed work	2.48*	0.015										
Coping strategies												
Done work more slowly than usual	−3.51***	<0.001			−3.10**	0.0027						
Interrupted work or left desk			2.98**	0.0039					2.43*	0.017		
Discussed noise problem with colleagues					3.48***	<0.001						
Made an even greater effort											3.80***	<0.001
Noise disturbance												
Intelligible speech					−2.56*	0.012						
Mental health												
Concentration	6.40***	<0.001										
Fatigue			11.26***	<0.001								
Productivity					7.20***	<0.001						
Job performance							4.29***	<0.001				
Exhaustion									9.10***	<0.001		
Tense arousal											7.25***	<0.001
Adjusted R-squared	0.44		0.55		0.43		0.20		0.57		0.45	

presence of external noise or arousal stimulating to overcome boredom and disengagement.

Furthermore, several coping strategies that were frequently used at the time of the pre survey, showed to have a significant influence on employees' perceived mental health at the time of the post survey. This suggests that some coping strategies may thus have been helpful while others might have worsened the situation, although unobserved confounders may have caused changes as well. Fig. 1 provides an overview of all significant relationships between coping strategies (pre survey) and mental health outcomes (post survey). The strongest relationships are highlighted in text here. First, workers who interrupted their work or left their desk felt more stressed in the post survey. Those who frequently coped with noise by putting on the radio or headphones as indicated in the pre survey showed more depressive symptoms in the post survey. Surprisingly, people indicated to feel less tense and nervous (tense arousal) in the post survey when they coped with noise by making an even greater effort. Employees who discussed the noise problem with colleagues in the pre survey felt more productive in the post survey. Employees who indicated coping with noise by doing work more slowly than usual in the pre survey felt less concentrated at the time of the post survey.

Regarding employees' work tasks, the SUR shows that employees who frequently had informal unplanned meetings at the time of the pre survey felt less concentrated and productive and were more disturbed by intelligible speech conversations at the time of the post survey. On the other hand, those who frequently collaborated on focused work felt more concentrated at the time of the post survey. Frequently having planned meetings increased feelings of fatigue and reduced overall sleep quality in the post survey in comparison to the pre survey, while frequently having telephone conversations decreased fatigue and increased well-being. In addition, employees who frequently performed individual routine tasks rated their overall sleep quality higher in the post survey. Last, frequent reading led to lower distraction rates in the post survey. Regarding tasks and coping strategies, employees who frequently had telephone conversations were more likely to cope with noise using an active approach by discussing the noise problem with colleagues, while they were less likely to avoid it by changing the workstation or doing work from home.

Employees who frequently wore headphones indicated higher concentration levels and felt less exhausted during the post survey. These employees also more frequently put on the radio or headphones to cope with noise. Employees who indicated that there were sufficient concentration spots at the office indicated to feel less exhausted in the post survey.

4. Discussion

4.1. Discussion and practical implications

This study aimed to explore the effects of level-adaptive sound masking on employees' noise disturbance, coping strategies used, and mental health of two independent organizations in [nationality disclosed for review], using a reliable experimental design with both intervention and control groups. This study adds important insights to existing research, as it shows that people exposed to level-adaptive sound masking felt less tense, nervous, and stressed than those who did not receive the intervention. To the best of the authors' knowledge, this is also one of the first studies to apply level-adaptive sound masking in an open-plan office environment. Sound masking may influence the more transient, momentary feelings, while the chronic mental well-being or ill-being aspects appear unaffected. Previous research indicated that, under steady-state masked conditions (61 dB(A)), employees

Table 10.2
Seemingly Unrelated Regression Analysis (2/3).

	Overall sleep quality		**Well-being**		**Sleep quality**		**Depressive symptoms**		**Hedonic tone**		**Disengagement**		**Stress**	
	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.
Intercept	9.76***	<0.001	7.23***	<0.001	7.78***	<0.001	5.55***	<0.001	1.58	0.12	5.15***	<0.001	3.29**	0.0015
Intervention floor (yes/no)													−2.71**	0.0082
Personal characteristics														
Age	−3.76***	<0.001	−2.89**	0.0050										
Work hours			−2.85**	0.0056					4.12***	<0.001				
Personality														
Neuroticism													2.86**	0.0056
Extraversion													2.57*	0.012
Agreeableness							−2.90**	0.0048						
Work tasks														
Telephone conversations			2.28*	0.025										
Planned meetings	−3.39**	0.0011												
Individual routine tasks	2.61*	0.011												
Coping strategies														
Made an even greater effort	−2.93**	0.0045							2.51*	0.014				
Put on radio/ headphones							3.87***	<0.001			3.12**	0.0026		
Interrupted work or left desk													−4.23***	<0.001
Tried to be quieter in hope others would be too							−2.10*	0.039					−2.77**	0.0072
Changed workstation or worked from home													2.73**	0.0079
Put work off till another time			−3.05**	0.0031										
Noise disturbance														
Noise outside											−2.15*	0.035		
Intelligible speech conversations			−2.38*	0.020										
Mental health														
Overall sleep quality	4.12***	<0.001												
Well-being			6.31***	<0.001										
Sleep quality					6.04***	<0.001								
Depressive symptoms							3.91***	<0.001						
Hedonic tone									6.19***	<0.001				
Disengagement											13.82***	<0.001		
Stress													9.01***	<0.001
Adjusted R-squared	0.26		0.33		0.27		0.21		0.45		0.65		0.47	

Table 10.3
Seemingly Unrelated Regression Analysis (3/3).

	Discussed noise problem with colleagues		Put on radio/ headphones		Changed workstation or done work at home		Distraction		Intelligible speech conversations		Unintelligible background speech		People passing by	
	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.
Intercept	0.41	0.68	1.26	0.21	0.73	0.47	3.26**	0.0016	1.97	0.052	6.34***	<0.001	7.38***	<0.001
Intervention floor (yes/no)			−2.01*	0.048					−4.11***	<0.001				
Personal characteristics														
Noise sensitivity									3.17**	0.0022				
Headphones			3.20**	0.0020										
Personality														
Neuroticism													−3.67***	<0.001
Extraversion							2.57*	0.012						
Work tasks														
Telephone conversations	2.20*	0.031			−2.17*	0.033								
Individual focussed work					3.04**	0.0033								
Reading							−2.24*	0.028						
Informal unplanned meetings									2.98**	0.0038				
Coping strategies														
Discussed noise problem with colleagues	5.57***	<0.001												
Put on radio/ headphones			6.32***	<0.001										
Changed workstation or done work at home					7.22***	<0.001								
Noise disturbance														
Distraction	2.37*	0.020					8.52***	<0.001						
Unintelligible background speech											5.44***	<0.001		
Intelligible speech			2.12*	0.037					9.03***	<0.001				
People passing by													10.51***	<0.001
Adjusted R-squared	0.34		0.55		0.33		0.38		0.53		0.16		0.41	

rate their arousal levels higher but experience less stress and distraction than under unmasked conditions (45 dB(A), but with peaks to 66 dB(A)) [30]. Although these results are obtained under different masking conditions than current study's results (SPL of 35 to 43 dB(A)) it confirms that sound masking may reduce stress levels due to fewer unpredictable peak sounds. As the changing-state hypothesis shows, sound streams with variable acoustic properties (e.g., individual voices in a multi-talker environment) are more distracting than steady-state sound streams [44].

The level-adaptive sound masking system complied with the general recommendations that were given by scientific literature (e.g., [18,25]). Under these recommendations, this study confirms that workers who were exposed to sound masking were significantly less disturbed by intelligible speech conversations. The increase in background noise level (at company 1 from 28.7 dB(A) to 41.9 dB(A) and at company 2 from 32.4 dB(A) to 42.6 dB(A)) at both organizations may have caused the perceived reduction in disturbance by intelligible speech. A previous field study also found reduced speech disturbance after acoustical improvements (i.e., reduced reverberation time from 0.46 to 0.39 s and increased background sound level from 36 to 42 dB(A) due to sound masking) [23]. However, in the field study by Lenne et al. [29] no significant reduction in employees' annoyance due to intelligible speech conversations after implementing sound masking was found. In their study, the maximum masking sound level of 45 dB(A) might have been too high (compared to a maximum masking sound level of 43 dB(A) in the current study), which might even have caused an adverse effect on noise annoyance. These field studies suggest that next to sound masking and absorption, the ambient noise level (L_{Aeq}) at the office should be minimized.

Effective remedies that facility managers and designers may consider are integrating an activity-based office design, improving the sound insulation of meeting rooms, and providing sufficient phone booths and concentration spots. For instance, it is important to design offices with sufficient spaces for concentration [32], as they may act as a job resource for employees to cope with noise, and, as this study showed, they may reduce feelings of exhaustion. Individual differences (e.g., noise sensitivity and personality) and job-related differences (e.g., task variety and concentration requirements) should also be regarded, as this study indicated that people who score high on neuroticism felt more tense and stressed, and people high on extraversion felt more stressed and distracted. These characteristics may also moderate the need for concentration spaces [20]. As Chafi et al. [13] suggest, workplace managers should aim for aligning the workplace to employees' needs since one-size-fits-all solutions to the workplace do not exist. In all workplace decisions, organizations should consider the position of employees as their mental well-being will be influenced by future workplace decisions [2].

Meanwhile, office workers have sought their own means to escape noise disturbance in the open-plan office, for instance through active noise-cancelling headphones [8]. Active noise-cancelling headphones are a complementary measure to subjectively improve acoustic satisfaction but are not a means to improve employees' cognitive performance [33]. The general population of the current study used the coping strategy of putting on radio or headphones when they felt distracted by intelligible speech. The results also showed that employees felt more disengaged and indicated more depressive symptoms in the post survey if they used this strategy to cope with noise. Active noise-cancelling headphones provide employees with more personal control over their acoustic space but may simultaneously cause detachment, while sound masking externalizes the acoustic control outside the individual. It will therefore maintain employees' availability for participation in the office environment [8]. Current study's findings showed that sound masking reduced the frequency with which people put on radio or headphones to cope with noise, which may potentially increase their engagement and involvement within the office. More generally, Hongisto [24] provided first evidence of a reduced need for coping strategies under masking

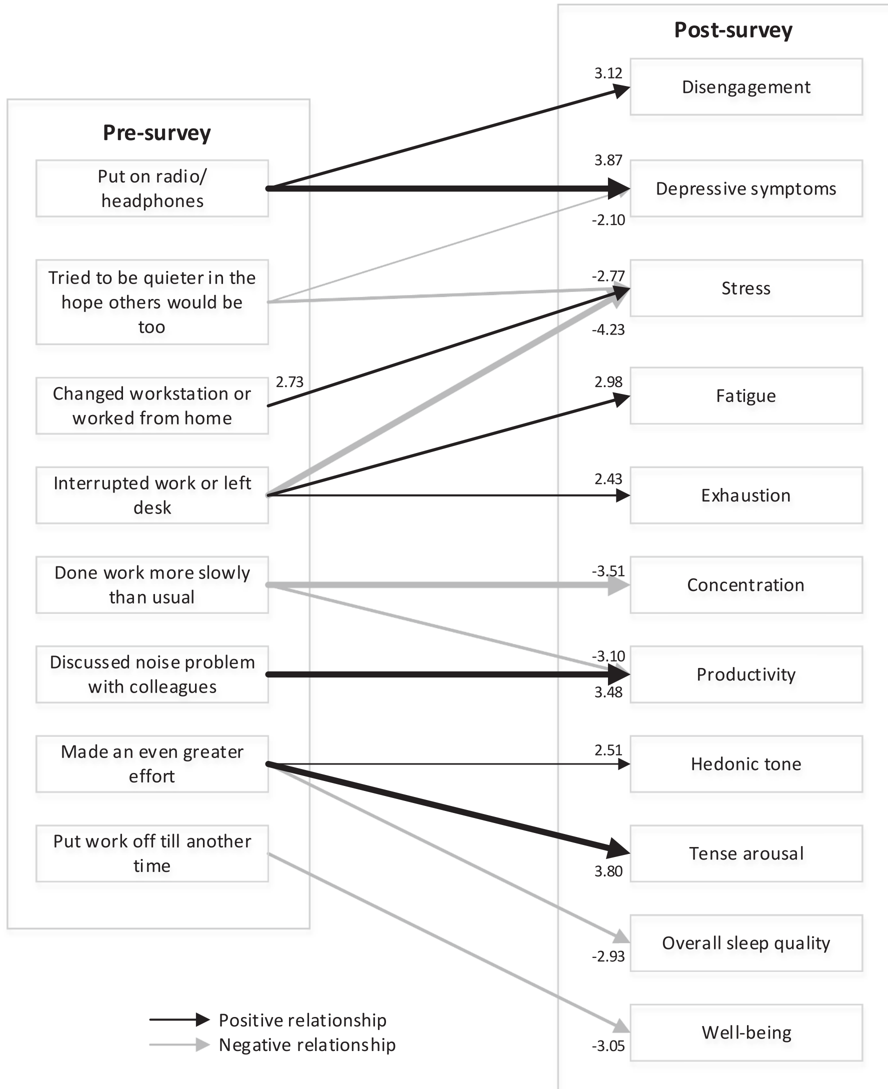

Fig. 1. Seemingly Unrelated Regression analysis – Relationships between coping strategies (pre-survey) and mental health indicators (post-survey).

conditions (A-weighted SPL of speech at 4 m of 51 dB(A), background noise level of 44 dB(A), and distraction distance of 6.2 m). It seems that a general approach to improve the acoustic design of the open-plan office, which is not limited to the introduction of sound masking, may reduce the need for individual solutions.

4.2. Limitations

Although this study obtained interesting findings, some limitations remain. First, data were gathered at two companies in [nationality disclosed for blinded review]. At both companies, more males than females responded to the survey, but especially at the first company males were overrepresented (N = 80 %). Since both organizations' populations consist of more males than females, the overrepresentation of males was not surprising. Nevertheless, the findings of the current study may therefore be hard to generalize to different contexts, countries or populations and should be carefully interpreted and replicated in other contexts.

Last, data were collected in the last months of 2022 and the first months of 2023. The Christmas holiday was included in the measurement period, which may have had an influence on people's mood, stress, and fatigue. Future studies should aim for a more consistent experimental phase, preferably during one season. It might also be interesting to consider a longer experimental phase, to observe whether the more chronic mental health characteristics change after long-term exposure to sound masking.

5. Conclusion and recommendations

This study aimed to get insights in if, and how level-adaptive sound masking could reduce noise distractions and increase mental health in an open-plan office environment. The novel application of level-adaptive sound masking in a longitudinal field study with an intervention and a control floor enriched existing knowledge so far. Findings show that level-adaptive sound masking significantly reduced people's disturbance by intelligible speech, and that the transient, momentary mental health aspects were rated more positively. Instead of individual solutions to cope with noise (e.g., active noise-cancelling headphones), general solutions (e.g., sound masking, high absorption in room surfaces and furniture, and activity-based working layouts) should be considered to improve employees' mental health while consistently regarding individual needs.

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CRediT authorship contribution statement

Lisanne Bergefurt: Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Rianne Appel-Meulenbroek:** Supervision, Writing – review & editing. **Theo Arentze:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Lisanne Bergefurt reports equipment, drugs, or supplies was provided by SoftdB.

Data availability

The authors do not have permission to share data.

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