



Bundesanstalt für Arbeitsschutz und Arbeitsmedizin

Sound Acoustics for Employees (SAFE)

4th and 5th of November 2015, BAuA, Dortmund

**A general survey on non-auditory
effects of noise at work places**

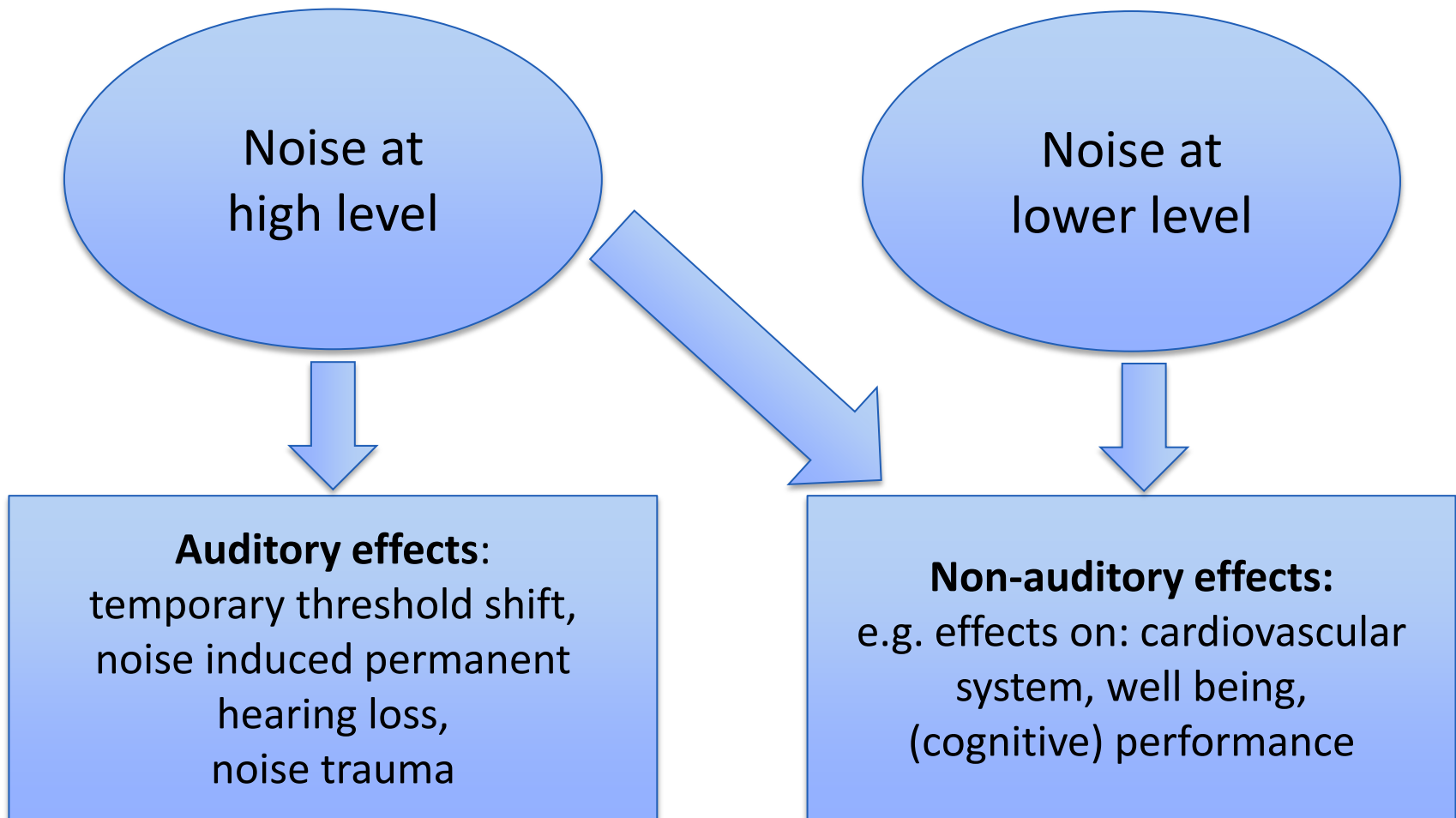
H. Sukowski, Unit Physical Agents, BAuA, Dortmund

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(1) Auditory and non-auditory effects of noise in general

Auditory and non-auditory effects of noise in general



(2) Why is noise at work a big issue, also irrespective of noise induced hearing loss?

(A) BIBB/BAuA employee survey 2012 (1/2)

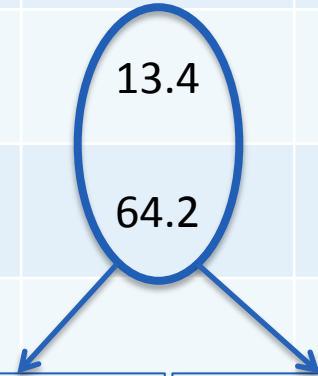
BIBB = Federal Institute for Vocational Education and Training

BAuA = Federal Institute for Occupational Safety and Health

- N=20,036 employees:
 - age >14 years
 - working hours per week >9 hours
- Telephone interview
- Items regarding noise (in the section “working conditions”):
 - working in noisy conditions: frequently, sometimes, rarely, never
 - if frequently, then: Is this stressful for you? - yes, no

(A) BIBB/BAuA employee survey 2012 (2/2)

Working conditions / Stressors		Unskilled or semi-skilled activities	Specialist activities	Complex specialist activities	Highly complex activities	Overall employees
...						
Working in noisy conditions	Percentage "frequently"	40.9	35.0	15.2	13.4	27.3
	Percentage stressed "yes"	41.5	48.5	48.5	64.2	49.4
...						



Results for fulltime employees
(Sicherheit und Gesundheit bei der Arbeit 2013 - Unfallverhütungsbericht Arbeit, page 279-281; www.baua.de/dok/5746626)

Male	Female
10.5	19.1
53.3	75.5

References

P. Wittig, Ch. Nöllenheidt, S. Brenscheidt: Grundausswertung der BIBB/BAuA-Erwerbstätigenbefragung 2012. mit den Schwerpunkten Arbeitsbedingungen, Arbeitsbelastungen und gesundheitliche Beschwerden 1. Auflage. Dortmund: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2013.
(www.baua.de/arbeitsbedingungen)

P. Wittig, Ch. Nöllenheidt, S. Brenscheidt: Grundausswertung der BIBB/BAuA-Erwerbstätigenbefragung 2012 - Männer/Frauen in Vollzeit. mit den Schwerpunkten Arbeitsbedingungen, Arbeitsbelastungen und gesundheitliche Beschwerden 1. Auflage. Dortmund: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2013.
(www.baua.de/arbeitsbedingungen)

Sicherheit und Gesundheit bei der Arbeit 2013 - Unfallverhütungsbericht Arbeit. 1. Auflage. Dortmund: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2014
(www.baua.de/suga)

(B) Workplace satisfaction in open-plan offices (1/2)

Kim, J. & de Dear, R. (2013). Workspace satisfaction: The privacy-communication trade-off in open-plan offices. *Journal of Environmental Psychology* 36, 18-26.

Method

- Under investigation: Satisfaction with “indoor environmental quality” in five different kinds of offices
- Kinds of offices:
 - enclosed private
 - enclosed shared
 - cubicles with high partitions
 - cubicles with low partitions
 - open office with no/limited partitions
- Questions regarding sound condition:
 - How satisfied are you with the *noise level* in your workspace?
 - How satisfied are you with the *sound privacy* in your workspace?
- Method: seven point scale from dissatisfied (-3) to satisfied (+3)

(B) Workplace satisfaction in open-plan offices (2/2)

Kim, J. & de Dear, R. (2013). Workspace satisfaction: The privacy-communication trade-off in open-plan offices. *Journal of Environmental Psychology* 36, 18-26.

Results

- “Noise level” and “Sound privacy” were rated more as “dissatisfying” in comparison to many other workspace conditions, e.g. “Amount of light” or “Amount of space”.
- Noise level: only positive mean values for shared and private enclosed offices; not for cubicles or open offices
- Sound privacy: only positive mean values for private enclosed offices; negative mean values for all other kinds of offices

(C) Sick leave rates in different types of offices

Bodin Danielsson, C., Chungkham, H. S., Wulff, C. & Westerlund, H. (2014). Office design's impact on sick leave rates. *Ergonomics*, 57(2), 139-147.

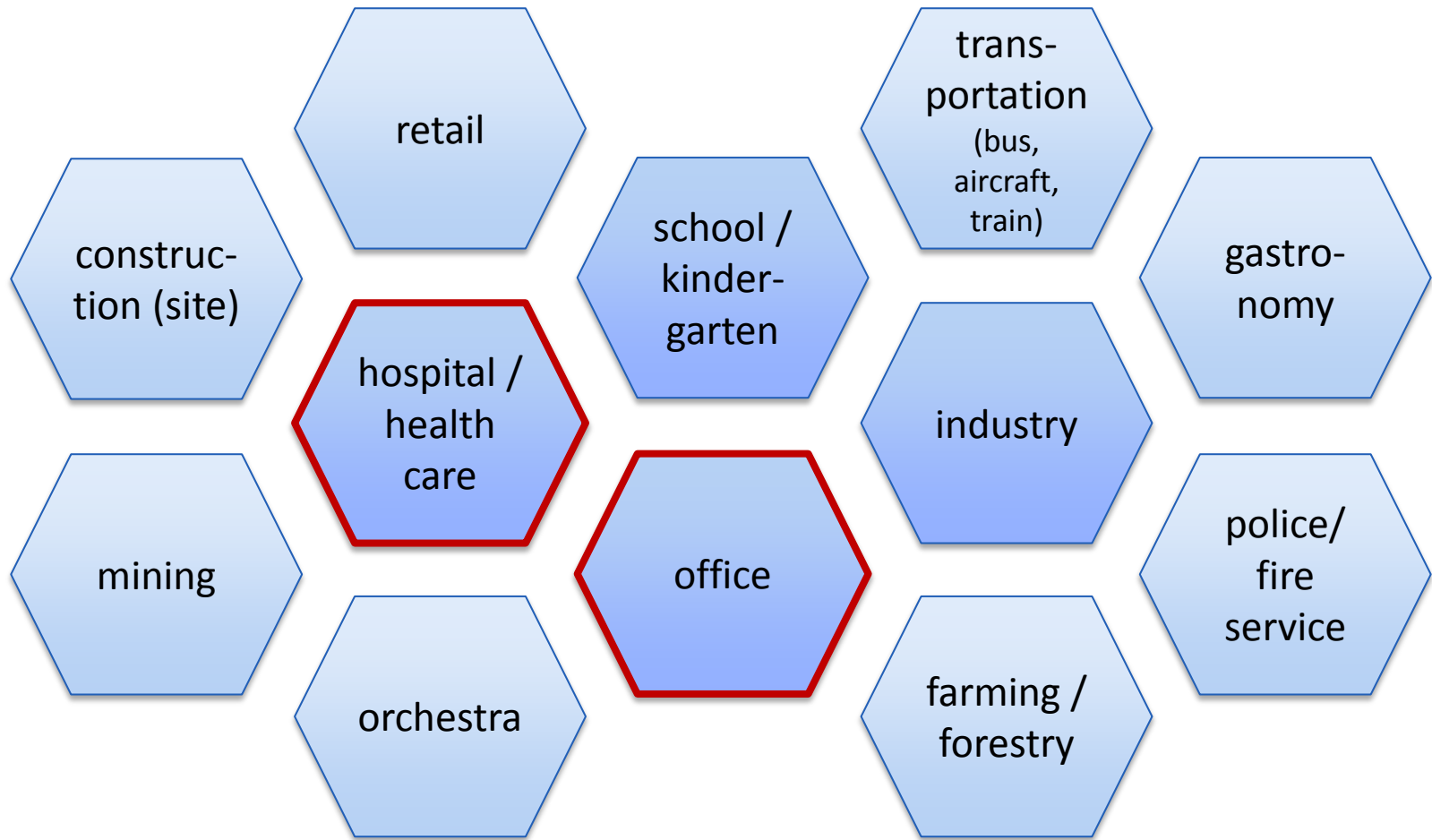
Under investigation: Seven different types of offices:
cell-offices; shared-room offices; small, medium-sized and large open-plan offices;
flex-offices; combi-offices

Results

- Short-term sick leaves:
 - significant excess risk for sickness absence in the three open-plan office types (also in a separate analysis for women)
 - significantly increased risk in flex-offices for men
- Long-term sick leaves:
 - significantly higher risk among women in large open-plan offices
- Total number of sick leave days:
 - significantly higher risk among men in flex-offices (p. 139)

(3) Working areas where non-auditory effects of noise have been a topic in the literature

Working areas where non-auditory effects have been a topic



Working areas summarised by Liebl & Kittel (2015), unpublished report

(4) Non-auditory effects of noise (at the work place)

Large variety of possible effects

performance

- working speed
- working accuracy
- productivity
- concentration
- wrong decisions
- reading
- ...

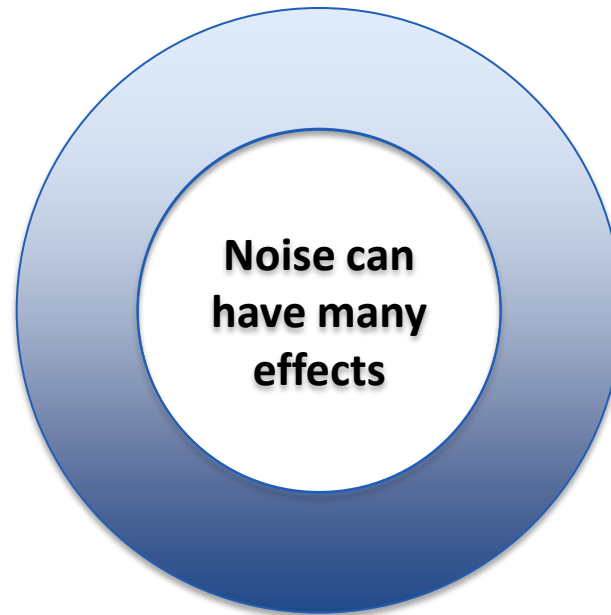
(social) behavior

satisfaction

motivation

communication

speech intelligibility



cardiovascular system

- blood pressure
- heart rate
- ...

physiological parameters

- stress hormones
- ...

musculoskeletal system

- upper limb disorder
- ...

psychological health / well-being

- perceived work load
- stress
- annoyance
- fatigue
- mood
- ...

Large variety of possible effects

performance

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- perceived work load
- stress
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- fatigue
- mood
- ...

Effects may be
interrelated

Effects are
examined to a
different extent
(see below)

Factors that can moderate / influence the effects of noise

non-acoustical factors

Personal factors:

- age
- gender
- noise sensitivity
- ...

Situational factors:

- time pressure
- task
- support by colleagues
- ...

acoustical factors

Aspects of the sound itself:

- duration
- frequency contents
- level
- ...

Other physical parameters:

- lighting
- climate
- workspace
- ...

References - dealing also with moderator variables

The following references include compilations of moderator variables or non-acoustic influencing variables:

Guski, R. (1987). *Lärm, Wirkungen unerwünschter Geräusche*. Bern: Huber.

Schick, A. (1997). *Das Konzept der Belästigung in der Lärmforschung*. Lengerich: Pabst.

Examples for well-known associations

Association between speech signals or other sounds with changing state (spectro-temporal variability) and mental performance

Well investigated for effects of speech signals on working memory.

Examples for recent studies:

Ebissou et al. (2014); Ellermeier & Zimmer (2014); Haapakangas et al. (2011); Haka et al. (2009); Jahncke et al. (2013); Liebl et al. (2011); Liebl et al. (2012); Llung et al. (2013); Park et al. (2013); Perham et al. (2013); Schlittmeier et al. (2008); Schlittmeier & Hellbrück (2009); ...

In this field there is / are:

- a lot of basic research
- research where this knowledge is applied on work-like situations
- studies where specific aspects are investigated

Examples for well-known associations

Association between speech signals or other sounds with changing state (spectro-temporal variability) and mental performance

Handbook of human performance

(Smith & Jones, 1992), Chapter I “Noise and performance”

(Smith & Jones):

“1. Several studies [...] have shown that performance is impaired if speech (but not white noise) is played while a subject learns and remembers verbal materials” (p. 11).

References (1/2)

- Ebissou, A., Parizet, E. & Chevret, P. (2014). Use of the speech transmission index for the assessment of sound annoyance in open-plan offices. *Applied Acoustics*, 88, 90-95.
- Ellermeier, W. & Zimmer, K. (2014). The psychoacoustics of the irrelevant sound effect. *Acoustical Science and Technology*, 35(1), 10-16.
- Haapakangas, A., Kankkunen, E., Hongisto, V., Virjonen, P., Oliva, D. & Keskinen, E. (2011). Effects of five speech masking sounds on performance and acoustic satisfaction. Implications for open-plan offices. *Acta Acustica united with Acustica*, 97(4), 641-655.
- Haka, M., Haapakangas, A., Keränen, J., Hakala, J., Keskinen, E. & Hongisto, V. (2009). Performance effects and subjective disturbance of speech in acoustically different office types - a laboratory experiment. *Indoor Air*, 19(6), 454-467.
- Jahncke, H., Hongisto, V. & Virjonen, P. (2013). Cognitive performance during irrelevant speech: Effects of speech intelligibility and office-task characteristics. *Applied Acoustics*, 74(3), 307-316.
- Liebl, A., Drotleff, H., Sedlbauer, K., Schleuniger, F. & Uygun, A. (2011). Room acoustical set values and measures for optimization of cognitive performance and acoustic comfort in open-plan offices. *BAUPHYSIK*, 33(2), 87-93.
- Liebl, A., Haller, J., Jödicke, B., Baumgartner, H., Schlittmeier, S. & Hellbrück, J. (2012). Combined effects of acoustic and visual distraction on cognitive performance and well-being. *Applied Ergonomics*, 43(2), 424-434.

References (2/2)

Ljung, R., Israelsson, K. & Hygge, S. (2013). Speech intelligibility and recall of spoken material heard at different signal-to-noise ratios and the role played by working memory capacity. *Applied Cognitive Psychology*, 27(2), 198-203.

Park, M., Kohlrausch, A. & van Leest, A. (2013). Irrelevant speech effect under stationary and adaptive masking conditions. *Journal of the Acoustical Society of America*, 134(3), 1970-1981.

Perham, N., Hodgetts, H. & Banbury, S. (2013). Mental arithmetic and non-speech office noise: an exploration of interference-by-content. *Noise & Health*, 15(62), 73-78.

Schlittmeier, S. J., Hellbrück, J., Thaden, R. & Vorländer, M. (2008). The impact of background speech varying in intelligibility: Effects on cognitive performance and perceived disturbance. *Ergonomics*, 51(5), 719-736.

Schlittmeier, S. J. & Hellbrück, J. (2009). Background music as noise abatement in open-plan offices: A laboratory study on performance effects and subjective preferences. *Applied Cognitive Psychology*, 23, 684-697.

Smith, A. P. & Jones, D. M. (1992). Noise and performance. In: Smith A. P. & Jones D. M. (Hrsg.), *Handbook of Human Performance*, Vol. 1: The physical environment (S. 1-28). London: Academic Press.

Example for other known associations

Effects of noise on the cardiovascular system

Recent overview in:

Handbook of Occupational Medicine, Letzel & Nowak (2014), in German
Chapter on extra-aural effects of noise by D. Twardella (2014)

Several indicators that noise is harmful, but only few significant results.

Studies that show significant effects:

Stress hormones: e.g. Ghotbi et al. (2013); Fouladi et al. (2012)

Blood pressure: e.g. Chang et al. (2013); Sbihi et al. (2008)

Risk for a heart attack: e.g. Gopinath et al. (2011)

Careful conclusion by the author: “There is increasing evidence that noise at workplace has an adverse effect on the cardiovascular system.” (Translation by the author of the presentation.)

Original: “Insgesamt verdichten sich die Hinweise darauf, dass Arbeitslärmbelastung eine schädliche Wirkung auf das Herz-Kreislauf-System hat” (Twardella, 2014).

References

- Letzel, S. & Nowak, D. (Hrsg.) (2014). *Handbuch der Arbeitsmedizin digital*. Landsberg/Lech: Ecomed Medizin.
- Twardella, D. (2014). Extraaurale Lärmwirkungen. In: Letzel, S., Nowak, D. (Hrsg.) *Handbuch der Arbeitsmedizin digital*. Landsberg/Lech: Ecomed Medizin, DII-2.3.
- Fouladi, D. B., Nassiri, P., Monazzam, E. M., Farahani, S., Hassanzadeh, G., & Hoseini, M. (2012). Industrial noise exposure and salivary cortisol in blue collar industrial workers. *Noise & Health*, 14(59), 184-189.
- Ghotbi, M. R., Khanjani, N., Barkhordari, A., Moghadam, S. R., Mozaffari, A. & Gozashti, M. H. (2013). Changes in urinary catecholamines in response to noise exposure in workers at Sarcheshmeh Copper Complex, Kerman, Iran. *Environ Monit Assess*, 185, 8809-8814.
- Chang, TY., Hwang, BF., Liu, CS, Chen, RY., Wang, VS., Bao, BY. & Lai, JS. (2013). Occupational noise exposure and incident hypertension in men: a prospective cohort study. *Am J Epidemiol* ,177(8), 818-825.
- Sbihi, H., Davies, H. W., & Demers, P. A. (2008). Hypertension in noise-exposed sawmill workers: a cohort study. *Occupational and Environmental Medicine*, 65(9), 643-646.
- Gopinath, B., Thiagalingam, A., Teber, E. & Mitchell, P. (2011). Exposure to workplace noise and the risk of cardiovascular disease events and mortality among older adults. *Preventive Medicine*, 53, 390-394.

Example for rarely investigated potential outcomes

Magnavita, N., Elovainio, M., De Nardis, I., Heponiemi, T., Bergamaschi, A. (2011). Environmental discomfort and musculoskeletal disorders. *Occupational Medicine*, 61, 196-201.

Questionnaires concerning (N = 1,744):

- occurrence of musculoskeletal disorders (MSD)
 - psychosocial factors at the workplace
 - physical environmental factors in the workplace
- => Question: “Have you been annoyed in the last 3 months by any of these factors in the workplace?”
- => One of the mentioned factors “noise” (never, sometimes, often)

Results:

“Environmental complaints were associated with MSDs. The strongest associations were found between temperature complaints (OR 2.73), noise and light complaints (OR 2.22), other environmental complaints (OR 3.12) and upper limb disorders” (p. 196).

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Conclusions “To prevent MSDs, a multi-level approach is needed, including environmental measures and interventions directed to both psychosocial and organizational factors” (p. 196).

(5) Intelligibility of speech: the listener's side

Intelligibility of speech - situations

Situations where good intelligibility is necessary and / or wanted

Situations where good intelligibility is not necessary and / or not wanted

Challenging situations

- Situations where good intelligibility between dialogue partners is wanted, but for others good intelligibility is not wanted
e.g. consulting at a counter (pharmacy)
- Situations with quick change between tasks with different requirements for the optimal acoustic conditions
e.g. working in open-plan offices (communication, concentration)

Intelligibility of speech - possible measurement

- Typical approach in the field of audiology: use of speech intelligibility tests (words, non-words, numbers, sentences) that can be applied in silence or noise to determine the hearing ability
- Typical measurement in this context: determination of the *speech reception threshold*, i.e. that signal-to-noise ratio (SNR) at which 50% of the spoken material can be understood

Intelligibility of speech - results from an evaluation study

Results from an evaluation study with the Göttingen Sentence Test (German speech intelligibility test by Kollmeier & Wesselkamp, 1997):

- At the steepest point of the discrimination function, an increase in the ambient sound (noise) level by one dB leads to a loss of intelligibility by about 20% in normal hearing listeners.
- That means: A small increase in the ambient noise level leads to a considerable loss in speech intelligibility.

Kollmeier, B. & Wesselkamp, M. (1997). Development and evaluation of a German sentence test for objective and subjective speech intelligibility assessment. *J Acoust Soc Am* 102(4), 2412-2421.

Intelligibility of speech

Loss of speech intelligibility in noise is a problem in situations where good speech intelligibility for all or for a subgroup is desired and / or necessary:

- additional noise disturbs the wanted communication
- additional noise is an additional burden, especially
 - for people with a hearing loss and
 - for non-native speakers

⇒ This holds for work place situations but also for other situations.

(6) Critical aspects - Knowledge gaps - Future approaches

Critical aspects - Knowledge gaps - Future approaches

(A) Test procedures to measure performance

- Different tests are used in different studies
 - Procedures are often available in one language only
- ⇒ *it is difficult to compare results from different studies*
- Procedures are not evaluated with respect to training effects
- ⇒ *training effects can mask the noise effect*
- Ecological validity: To what extent are the procedures representative for real work situations?

We have to keep an eye on the quality, comparability and the universal validity of the applied measurement tools.

Critical aspects - Knowledge gaps - Future approaches

(B) The participants and kinds of studies

- Effects (on performance) are often investigated in volunteers from university, not in real employees
- Rarely consideration of vulnerable people
- Often cross-sectional studies without repeated measurements
- Strong focus on performance
- Less consideration of health effects

Field studies are needed that also investigate the non-auditory effects of noise with real employees, in consideration of vulnerable groups (e.g. employees with a hearing loss) and of a larger variety of possible long term outcomes.

(C) Knowledge about the sound parameters that cause adverse effects

Which sound parameters (in addition to level and speech intelligibility) should be used to assess the effects of noise, in order to protect employees from adverse effects at the workplace?