Review of research on the effects of noise on cognitive performance 2017-2021

Sabine J. Schlittmeier[1], John E. Marsh[2,3]

[1] RWTH Aachen University, Institute for Psychology, Aachen, Germany (corresponding author)
[2] University of Central Lancashire, School of Psychology and Computer Science, Preston, Lancashire, United Kingdom
[3] University of Luleå, Department of Business Administration, Technology and Social Sciences, Humans and technology, Luleå, Sweden

Corresponding author's e-mail address: sabine.schlittmeier@psych.rwth-aachen.de

ABSTRACT

Corresponding to the topics of Team 4 of the International Commission on Biological Effects of Noise (ICBEN), a literature review is presented covering the years 2017 to 2021 with a focus on the effects of noise on cognitive performance and the methods used to study these effects. We used sound or noise and cognitive performance as well as several related terms in the search string. Using a stepwise procedure, we reduced 1410 records to 70 reports for inclusion in the literature overview. Since task-irrelevant background speech is considered one of the main acoustical challenges for work-places at which predominantly cognitive performance must be achieved, we included 8 further cognitive-psychological reports, which explored how and why task-irrelevant background speech and its characteristics affect cognitive performance. Thus, the overall amount of included reports in the present literature overview is 78, each reporting at least one original empirical dataset on the effects of noise on cognitive performance. We analysed the results of the selected 78 empirical reports and discussed the main trends in terms of topics and methodologies.

LITERATURE SEARCH

A literature search was conducted covering the years 2017 to 2021 in the “Web of Science Core Collection”, namely on the Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index - Science (CPCI-S), Conference Proceedings Citation Index - Social Sciences & Humanities (CPCI-SSH) and Emerging Sources Citation Index (ESCI). The search string was designed without truncations but with phrases, and searches included titles, abstracts and keywords:

ALL=("Noise" OR "Sound") AND ALL=("Cognitive Performance" OR "Cognitive work" OR "Cognitive activity" OR "Cognitive Ability" OR "Cognitive task" OR "Mental Work" OR "Mental task" OR "mental processing" OR "memory task" OR "working memory" OR "Executive function" OR "Attentional focus" OR "Attentional capture" OR "Problem solving" OR "adaptive behaviour" OR "human behaviour" OR "speech intelligibility" OR "Coping") AND ALL=("Work" OR "Job" OR "public place" OR "in public" OR "dwelling" OR "building acoustics")

Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2017-2021

Using this search method and the procedures described in the following, altogether 78 empirical reports have been included in the literature overview [1-78].

We ran the search string on 1st April 2021, which resulted in the identification of 1410 records. These records were then reduced following the PRISMA 2020 scheme [79]. Before screening, 272 records were removed because they obviously did not match the intent to present an overview of empirical reports (e.g. duplicates, tables of contents, editorial statements, announcements, letters to the editor). The abstracts of the remaining 1138 records were screened which resulted in the exclusion of 735 more records because these did not match the area of interest. Thus, 403 reports were sought for retrieval of which 24 could not be retrieved. Since the latter were also excluded, 379 reports were assessed for eligibility. In this process, 309 reports were excluded due to at least one of the following reasons: (i) already reported in the last ICBEN review [80], (ii) the topic of the report fell outside of ICBEN area 4 (e.g. speech intelligibility when exploring hearing in noise, which falls into ICBEN area 2), (iii) no report of original empirical data (overview articles, meta-analyses, reviews), (iv) no adult participants (e.g. reports exclusively focusing on children; yet reports on teachers have been included since area 4 focuses on work places), (v) reporting exclusively neurophysiological measures.

This procedure resulted in 70 reports being included in the present literature overview [1-21, 24-36, 38-46, 49-66, 68-71, 73, 75-78]. We additionally included 8 further empirical reports [22-23, 37, 47-48, 67, 72, 74], the rationale behind this is described below. Thus, the overall amount of included reports is 78, each reporting at least one original empirical dataset on the effects of noise on cognitive performance [1-78].

The presence of task-irrelevant background speech while undertaking predominately cognitive performance, is considered as one of the main acoustical challenges for work-places. We therefore additionally searched for basic research reports on how and why irrelevant speech and its characteristics affect cognitive performance (e.g. by capturing one’s attention or producing interference in short-term memory). In the end, we were able to include 8 more reports in our overview that were not found in the search-string based literature search [22-23, 37, 47-48, 67, 72, 74]. We decided to keep reports in the overview that fulfilled the search string but did not test background speech as a noise condition [e.g. 4]. However, we refrained from additionally searching for, and including, basic research studies that did not test speech signals, but exclusively focused on performance effects attributable to to-be-ignored non-speech sounds like music or tone sequences.

Note, that we decided not to limit the overview to studies reporting objective measures of cognitive performance. Instead, we retained studies in the overview that solely reported subjective ratings on perceived performance [2, 3, 5, 19, 20-21, 24, 29, 34, 39, 54]. This takes into account field studies facing certain restrictions which often do not allow researchers to collect objective performance measures under controlled and systematically varied noise conditions of interest. However, since it is often the case that valuable impetus for further research, as well as insights for recommendations, can come from field studies, we did not want to exclude those field studies that fulfilled the search string from our overview by a strict criterion for objective performance data.

LITERATURE REVIEW

General information

In order to pre-structure the overview of the empirical reports published in the years 2017-2021, the included reports were first divided into two groups. From the total amount of 78 reports, 23 reports that, in our view, could be classified as applied research were grouped together in one group [1-3, 5, 13-14, 18-21, 24, 27, 29, 30, 34, 38-40, 42, 54, 71, 76, 78]. The compiled information on these reports can be found in Table 1 in the appendix. The other 55 reports that we consider to be more related to basic research, were grouped together in a second group [4, 6-12, 15-17, 22-23, 25-26, 28, 31-33, 35-37, 41, 43-53, 55-70, 72-75, 77]. The aggregated information on this group of reports is depicted in Table 2 in the appendix.

Obviously, the assignment of a report to one of these two groups could hardly be made according to a strict criterion. Therefore, we assigned a report to the group of applied reports if, for example, a field study was reported (e.g. in open-plan offices, banks) [e.g. 3, 5, 19, 21, 27, 29, 34, 54], if a certain work-space or work-place (open-plan office, open-plan study environment) was considered [e.g. 14], or if noise was considered as one of several multimodal stressors (e.g. temperature, lighting) [1, 13].

In the following, we focus first on key aspects of the applied research reports before turning to the more basic research reports.

Applied Research Reports

Sound Quality

Most of the applied studies in the considered period 2017-2021 dealt with background speech [2, 14, 18, 30, 76], office noise [3, 5, 20-21, 29, 38, 39] and/or masking sounds for noise abatement [2, 24, 30, 38-39, 40, 42, 78].

Most field studies, by their very nature, examined noise scenarios without further systematic variations or treatments [3, 5, 19, 21, 29, 34]. However, one field study [27] examined the effects of relocation from one office concept to another by means of cognitive performance measures during the resulting office noise conditions (serial recall task). The second study [54] focused on the effects of an acoustic treatment of a school on teachers' (and students') subjective evaluations.

In laboratory studies a variety of systematically varied noise conditions were examined. Most often background speech, including single [e.g. 2, 78] and multi-talker speech [e.g. 14, 76], as well as semantically meaningful speech and foreign language [e.g. 14] was examined. Yet also music [18], noise bursts [2] as well as natural and urban soundscapes [71] were tested. In most laboratory studies, a quiet condition was included as a reference auditory condition. In addition to auditory-only variations, single studies realised audiovisual experimental conditions to examine the impact of additional and/or varied visual input on subjective assessments [2, 42]. To our surprise, only a few applied studies applied auralization techniques to generate the sound conditions of interest, this was done, for example, to render different spatial source locations [76] or different reverberation times [14].

Speech Intelligibility and Level

Several of the applied studies examined whether the effects of background speech on cognitive performance and subjective evaluations depend on the intelligibity of background speech. Intelligibility was calculated instrumentally in the form of the Speech Transmission Index (STI) or related measures [e.g. 2, 3, 14, 19, 40]. In some field studies, distraction distance (r_D) has also been reported [e.g. 19, 21, 24]; it describes the distance at which the Speech Transmission Index (STI) falls below 0.50. Yet note that further acoustic measures such as spatial decay rate of speech ($D_{2,S}$), or speech level at 4 m distance ($L_{A,S,4m}$) have been reported in various studies, but are not fully listed in Table 1 in the Appendix.

In some studies on the effects of masking sounds, the SNR (signal-to-noise ratio) between the speech sound to be masked and the masker was deliberately varied [e.g. 14, 30, 40, 78], and so was speech intelligibility. Furthermore, the STI was also varied due to room parameters (cf. e.g. [14]). However, a systematic level variation was not the subject of the applied reports included in the review. The level was often reported as the A-weighted equivalent sound level (L_{Aeq}). Most applied studies presented - or found in the case of field studies - background sounds in a moderate range of about 40-60 dB(A) L_{Aeq} - but background sounds of 70 dB(A) or greater have also been reported [1, 13, 18, 20, 71, 85].

Cognitive performance during noise - objective measures

Not all applied research reports collected objective performance measures by presenting participants a specific cognitive task and measuring task performance, as mentioned above. Most studies that took objective measures of cognitive performance usually did so while utilising only one cognitive task (but cp. e.g. [30]) to compare the effect of different sound conditions on cognitive performance. Here, the verbal serial recall paradigm [27, 30, 76, 78] is still used most frequently, in which unrelated verbal items (e.g. letters or digits) are presented one after the other and are to be reproduced afterwards in their exact presentation order. This is a standard paradigm in cognitive psychology that it used to measure short-term memory. Several studies also report the use of further standard paradigms from basic research, like free recall [13], n-back [1, 13], visual search [42], forced choice ([18]; here as a so-called image interpretation task), stroop and flanker tasks [38]. However, several studies also used tasks tapping more complex cognitive performance, like mental arithmetics [30], proofreading [30], reading comprehension [30, 40] or a semantically-based collaboration task [14]. It is worth noting that all these cognitive tasks were presented visually. Reported performance impairments under noise cannot therefore be due to partial masking of the task material or by increased listening effort. However, the fact that there are no reports with auditory item presentation in the current selection is also due to the fact that we excluded all studies that focused on speech intelligibility in noise or auditory effort, as these topics fall within ICBEN Area 2 (and are outside the remit of the current ICBEN Area 4 overview).

Subjective measures targeting cognitive performance

The effects of noise on cognitive performance can be assessed both objectively, through performance measurements, and subjectively through the collection of assessments of participants' perceptions. In the latter case, participants are presented with a questionnaire or single scales on which they are asked to rate a specific aspect. In terms of subjective evaluation of one's cognitive performance, some studies asked their participants to rate perceived performance [24, 39, 40], perceived productivity [5] or perceived satisfaction with performance [38]. Several studies targeted the perceived difficulty of task completion during background noise or the effort involved, namely participants were asked for judgments on perceived task load or workload [5, 20, 30, 78], perceived mental effort [13] or perceived task difficulty [34]. Finally, several studies' ratings focused on the background sound by presenting participants with scales to assess perceived disturbance [3, 14, 38, 40, 78] or perceived distraction [24, 34].

It can be seen that a whole range of different subjective measures were collected in the compiled applied studies. And even if there are certain similarities regarding addressed concepts or constructs, the same items or scales were used in exceptional cases rather than as a rule.

Subjective measures of annoyance, mood and satisfaction

Noise-induced annoyance was also considered in several of the applied studies [19, 20, 24, 39, 42]. These studies measured noise annoyance mostly on 5-point or 7-point ratings scales; however, a 100-point scale was also reported [19]. Noise annoyance as the subjective experience of displeasure, nuisance, disturbance, or irritation caused by unwanted sound, might also be related to mood, which was also measured in several of the applied studies [e.g. 14, 42, 71]. Finally, several studies asked their participants to rate environmental satisfaction or acoustic comfort [2, 24, 29, 39-40, 78]. This approach widens the focus in the subjective assessment of background sound beyond possible negative aspects.

Further reactions to noise and mediators

In addition to the dependent and independent variables mentioned so far, the applied research reports have addressed a number of other aspects, like reported coping strategies during noise [3, 5], restorative effects [42, 71], health indicators and neurophysiological responses [1, 13, 20, 38, 42]. A number of variables were also examined for their role as mediators of noise reactions, such as, for example, the presence of visual input [2], sound preferences [3], age [30], one's role in a surgical team [34], or noise sensitivity [14, 20, 78].

A Summary of Empirical Findings from the Applied Research Reports

The focus of most applied studies centres on office noise and background speech, which is probably due to the fact that office and office-like workplaces are nowadays one of the most common workplace types. In group and open-plan offices, background speech from colleagues at distant workplaces is the dominant noise problem for employees who are supposed to do concentrated silent work. Since complete silence cannot be achieved in occupied group and open-plan offices, the challenge is to create acoustic conditions that have as little negative impact as possible on both cognitive performance and subjective well-being. However, many applied studies in the period 2017-2021, especially the field studies, are not (yet) concerned with abatement measures, but with examining the given acoustic conditions and the potential correlations with (objectively measured or subjectively assessed) cognitive performance and/or subjective evaluations.

The discussion that has often been held in recent years as to whether sound masking is a necessary part of the solution to noise at workplaces, now seems to have motivated quite a number of applied reports to turn their attention to the potential of additionally playing back partial maskers. Not only has the SNR to the noise to be masked been varied and the corresponding effects on performance been investigated, but also different kinds of maskers apart from continuous broadband noise as a kind of "standard" masker, e.g. springwater sounds. And, importantly, the idea seems to have been pushed back that the only criterion for the suitability of a masker is its potential to reduce intelligibility of background speech and the corresponding adverse performance effects. Instead, subjective assessments of different maskers and masking conditions are now also considered.

The field studies in the period considered by the current overview often did not collect objective performance measures. This is certainly due to the fact that it is difficult to get permission by companies for employees to work on non-work tasks during working hours and/or by staff councils for taking performance measures. And even if objective performance measures were permitted, it may be that the existing background noise is simply not typical of the environments under investigation, so that the informative value of the results would be reduced. Furthermore field studies often aim to assess the medium and long-term effects of specific office situations or characteristics. In the reporting period, the literature search yielded only one intervention field study wherein subjective judgements were collected before and after optimization measures and were even supplemented with data from a control group [27]. Since such studies can be realised only with an enormous effort and on certain occasions, it is not surprising that such studies are rarely carried out and even more rarely published as peer-reviewed publications due to the considerable methodological demands.

Basic Research Reports

Sound Quality

Most of the basic studies in the 2017-2021 period included background speech [6-12, 15-16, 22-23, 25-26, 28, 31-33, 35-37, 43-45, 47-48, 50, 52-53, 60-65, 68-70, 72, 77] that was sometimes vocoded [16, 65-66, 68, 75] or masked [26, 41, 53, 55-59]. Some studies manipulated the language or meaningfulness of the speech [9, 44, 47-48, 68, 72, 77] or its semantic similarity to the memoranda [22-23]. Other studies used piano notes [4] or melodies [61], tones [46-47, 65, 73] or instrumental sounds [12, 15, 17, 33]. Some deployed environmental noise [51, 74], broadband noise [49-50, 52], or bursts of broadband noise [43, 46, 72]. Most studies included quiet as a baseline condition but sometimes broadband noise was used instead [e.g., 33].

Speech Intelligibility and Level

Many reported manipulations within the basic studies reduced the speech intelligibility of to-be-ignored sound without any objective measurement of speech intelligibility per se. For example, several studies used noise-vocoded speech [16, 65-66, 75]. One study manipulated the spectral content and the envelope of speech independently [65]. Methods to manipulate intelligibility also included time-reversal of local (short-segments) as compared to longer segments [68]. Further, masking sounds were introduced in several studies to manipulate SNR [26, 41, 52, 53, 55-59], whereby the masker was either a speech signal [26, 55-59] or broadband noise [41, 53, 55]. Reported sound levels in the basic studies varied from 55 dB(A) [28, 49] to 75 dB(A) [50] and sound pressure was usually measured on a A-weighted scale.

Cognitive performance during noise - objective measures

The majority of studies used the visual-verbal serial recall task [4, 7-12, 16-17, 25, 28, 31, 33, 35-36, 43, 52, 55-66, 68-70]. However, a few used auditory-verbal serial recall [33, 37, 75] and some required backward digit [26] or word [53] recall. A single study used a probe task involving serial-short-term memory [28] while a number of others used a non-serial short-term memory task: the missing-item task [16, 25, 28, 31, 45]. One study used tonal sequence recognition and phoneme sequence recognition and recall [15] and another used a serial recall task for tonal and verbal material [33]. Several studies used eye-tracking measures while reading for meaning [48, 72-74, 77] or for non-character detection [48]. Cued recall was adopted in two studies [22, 49]. Other infrequently used tasks included free recall [23], psychomotor speed, continuous performance, trail making, odd-even number sequencing [44], grammatical reasoning, mathematics [49], stroop, response inhibition [51], key combination discovery [50] and a search for target material in tabulated information [44].

Subjective measures targeting the effects of noise on cognitive performance

A few of the basic studies administered questionnaires in relation to environmental satisfaction (acoustic comfort [41]), the unpleasantness of noise [50] and its perceived annoyance [51, 55-59]. These involved either marking a point along a line anchored at either end [50], a visual analogue scale [51] or a multi-point Likert scale [55-59].

A Summary of Empirical Findings from the Basic Research Reports

Two main research lines can be identified in the basic science reports. On the one hand, there is a focus on the question of which characteristics of task-irrelevant sounds determine their potential to impair cognitive performance. On the other hand, the cognitive processes vulnerable to background sounds are under consideration. Both strands of research are obviously not independent of each other but approach the question of "which sound interferes with which cognitive performance" from different directions.

Let us first consider the basic research reports focusing on different characteristics of task-irrelevant sound and their propensity to disrupt task performance, namely (usually) visual-verbal task performance. In this context, there has been an increased focus on the semantic properties of sound and their propensity to produce disruption over and above acoustic properties. There has also been a continued focus on the psycho-acoustical elements of speech with closer approximations to natural speech typically producing more disruption of tasks involving serial short-term memory [16, 65, 66] but not non-serial short-term memory tasks [16], with spectral changes playing a primary role [65]. Generally, a growing body of work has sought to determine the impact of different masking conditions on visual-verbal serial recall performance [55-59] and a trade-off between the effectiveness of the masker (at various SNRs or spatial set-ups) with reduced objective performance decrements that are sometimes accompanied with increased subjective annoyance from the masker being reported [55]. Previous work demonstrating that speech intelligibility plays a role in the disruption of visual-verbal serial recall has been replicated in a virtual reality setting [52] thereby validating this method for future research.

Several studies have further addressed the additional disruption that the (semantic) meaning of task-irrelevant speech has on visual-verbal task performance. The meaning of task-irrelevant speech was found to be disruptive of visual-verbal serial recall with segmental reversals of longer duration (thereby reducing speech intelligibility) reducing the disruption produced by speech within a participant’s spoken, but not non-spoken, language [68]. In this context, the field has also observed a wave of research investigating the impact of task-irrelevant sound on eye-movement measures during reading. These are online behavioural measures used to infer cognitive processing. Meaningful speech (e.g., in a language spoken by the participant), as compared to meaningless speech (e.g., in a language unknown by the participant, or spectrally altered), increases re-reading of text [73, 77] and disrupts reading comprehension when re-reading is prevented [73] suggesting that comprehension processes (e.g., integrating text into a coherent discourse) are disrupted by meaningful speech. The disruption produced by meaningful speech has also been shown to be modulated by the characteristics of the focal reading task: It occurs when participants have to decide whether sentences make sense, but not when a non-character has to be searched for within the sentence [48]. This study and others show that the question of performance-reducing sound characteristics and the question of cognitive processes that are vulnerable to task-irrelevant sounds cannot be considered independently from one another.

Within the line of research that is dedicated to the elucidation of the cognitive processes underlying a disruptive effect of task-irrelevant sound, the question of whether the disruptive effect on attentional processes - as one specific cognitive function besides others - can be managed and controlled still features prominently. In this context, it has been shown that increasing task-engagement by making text difficult to read by means of, for example an unusual font reduces disruption by meaningful speech in various tasks [6, 44-45]. Furthermore, foreknowledge - through prior exposure to a subsequently ignored meaningful sentence - reduces the disruption produced by that sentence [8, 25]. Disruption by predictable as compared with unpredictable auditory sequences has also been investigated but with mixed results [8, 25, 62, 64]. This line of research also includes the investigation of the role of person-specific perceptual and cognitive characteristics for detrimental noise effects. Here, it was shown that working memory capacity [35] or auditory global pattern matching ability [17] did not modulate the disruption of visual-verbal serial recall produced by task-irrelevant sound. Surprisingly, however, extensive auditory training has been shown to attenuate the disruption in the visual-verbal serial recall setting [32].

Finally, work has established that the disruption produced by sound on visual-verbal serial recall does not occur simply because participants have an expectation that the sound will disrupt their performance [61]. Moreover, although participants have been shown to be aware of the disruption produced by speech on free recall of word lists, they fail to adjust, when possible, presentation rates to compensate for this performance decrement [23].

CONCLUSIONS

This overview demonstrates that there is some overlap between the aspects targeted by applied and basic research reports from 2017-2021, while there is also a clear separation. We would like to conclude by addressing these two perspectives.

In our view, the most striking overlap between applied and basic research reports is in the interest in masking noise to combat negative noise effects, particularly those from background speech. The superimposition of office noise or especially background speech with a partial masker alters the overall sound signal for the involuntary listener in several ways. On the one hand, reduced speech intelligibility results in a reduction of the semantic content (e.g., meaning) of the background speech. With this, the resulting overall signal produces less disruption of cognitive performance that is ordinarily produced by the concurrent, semantic processing of speech including that underpinning reading comprehension, text recall or semantically-oriented proofreading (vs. searching for typographical errors). The reason for this lies in the so-called "interference of process principle" (cp. [81]). Even if background speech is irrelevant and one intends to ignore it, the speech signal is automatically and obligatorily processed by the listener`s auditory-perceptual and cognitive systems. Evidence suggests that this obligatory processing may include semantic analysis of background speech. When background speech is meaningful, these automatic sound-related processes can interfere with corresponding semantic-based processes involved in task performance. Thus, the greater the reduction in (and thereby processing of) the semantic properties of background speech, the less the speech signal will interfere with performance on semantically-based tasks. On the other hand, the introduction of a partial masker also reduces the temporal-spectral variability and distinct temporal structure of the overall background sound. But it is precisely this acoustic variability and structure that endows the background sound with its power to disrupt verbal short-term memory (cp. [82]). Therefore, the introduction of a partial masker usually also reduces the disruptive impact of the overall background sound on visual-verbal serial recall, which is the standard measure of verbal short-term memory. Thus, partial maskers can reduce the disruptive impact of speech and other background sounds in a wide variety of tasks, but the underlying causes or cognitive mechanisms of action can be fundamentally different in each case. The reports in this overview illustrate that from an applied research perspective, the overarching potential of masking sounds in noisy work environments to reduce cognitive disruption is of particular interest, while the basic research reports focus on elucidating the underlying cognitive mechanisms of action in each case.

Another area of overlap between applied and basic research reports is the very common use of the aforementioned visual-verbal serial recall task in the considered period. This might be due to two different reasons: First, performance in this task has been shown to be very sensitive to disruption from task-irrelevant sound. Second, this task allows the impact of several noise conditions to be measured and evaluated within one experimental group, which is very time efficient. Third, from the point of view of basic research, there is broad agreement among cognitive psychologists concerning the processes underpinning the task. However, as cognitive psychologists, we must also point out that this task measures a very specific cognitive performance, namely the capacity to retain sequences of visual items over the short term. According to the cognitive-psychological information processing approach, it is assumed that complex cognitive performance involved in, for example, understanding a read or heard text, is achieved through the interaction of a limited number of basic cognitive functions, only one of which is short-term memory. Other basic cognitive functions are, for example, attention and executive functions. However, the overview shows that other cognitive tasks and functions, respectively, are examined less frequently. Since they are potentially disrupted by sound characteristics other than those which disrupt verbal short-term memory, as described above, the dominant use of the verbal serial-recall task might not be as helpful in applied contexts as it might appear at first glance.

This applies, for example, to the challenge of acoustically optimising workspaces for certain cognitive performances. For example, if a substantial part of the work in an architectural or construction office is based on the accomplishment of spatial tasks, then from a cognitive psychology perspective, verbal tasks such as proofreading or verbal serial recall probably do not capture the cognitive processes of interest. Accordingly, it is questionable to what extent research results obtained from verbal tasks indicate the disruptive effect of existing office noise or the beneficial effects of certain optimisation measures on the predominantly non-verbal cognitive performance that is actually of interest.

In addition to the aforementioned parallels between applied and basic research in the reporting period, we also noticed at least two striking demarcation lines. Firstly, there is an asymmetrical distribution in the extent to which objective and/or subjective data are collected. Many of the applied studies collected subjective ratings and field studies often exclusively focused on such data. In basic research studies, however, there was often a restriction to objective performance measurements; subjective assessments concerning whether one felt disturbed and/or annoyed by certain background sound conditions were rarely made. The omission of either subjective or objective assessments certainly has to do with various practical and methodological aspects. In field studies it may not always be possible to collect performance data, as already described above. Furthermore, subjective assessments might be of apparent relevance for researchers in the applied context as the concept of annoyance has much more awareness here, since, for example, a certain proportion of "Highly Annoyed" (HA) persons in a population is the reference for legal regulations of traffic noise in many countries. Finally, many studies that collect both objective performance data and subjective judgements probably share the belief that “feeling disturbed” and “being disturbed” are two different or even independent effect dimensions of noise which both need to be considered for human-centred evaluation of the acoustic environment. In the basic research reports, however, cognitive psychology research interests are often - and legitimately, of course - in the foreground, such as the question of which sound characteristics are processed obligatorily and automatically, which characteristics a task must possess for it to be vulnerable to disruption, and how precisely the mechanisms behind a sound-induced performance decrement operate. In this context, participants are rarely asked whether they feel disturbed by a certain background sound. Indeed, such a question appears somewhat peripheral to the main goals of such studies.

A further difference between applied and basic research reports is apparent regarding the background sound conditions considered. Although background speech plays an essential role in both research fields, there are very different aspects and characteristics of speech that are considered and, if applicable, also deliberately varied. For example, in basic research reports meaningless foreign speech, taboo words or sequences of different syllables are considered, that appear to be of little interest in the applied context wherein sound pressure level and intelligibility are of central interest. Since background speech is often investigated with respect to a given room or certain room characteristics, room acoustic parameters are also measured or even varied, for example the reverberation time or spatial decay rate of speech. The report and consideration of these room acoustic parameters corresponds with the ISO 3382-3:2012 [83] and its recommendations for the evaluation of the acoustics of an open-plan office. This will not change with the recently published ISO 22955:2021 [84]; rather, this standard further emphasises the need to distinguish between different types of work (individual concentrated work, collaborative work and call centres) and the specific acoustic optimisation of work environments for each.

This brings us back to the tasks used and the current dominance of the highly specific visual-verbal serial recall task. Certainly, there were a number of reports in the period under consideration that applied other cognitive tasks to investigate noise effects on cognitive performances. These reports often justified task selection by referring to the relevance of certain task performance, cognitive processes or functions at the workplaces under consideration. As cognitive psychologists, we hope that the demand for cognitive tasks beyond visual-verbal serial recall will continue to grow from the applied research community. We also hope that this will motivate the basic research community to develop and provide corresponding cognitive tasks that, at best and like the serial recall task, are suitable for comparing the effects of different acoustic conditions using just one sample. Although our hopes are tempered with the caveat that it is a goal of cognitive psychologists to understand the mechanistic processes underpinning a task, prior to understanding how it could be susceptible to disruption from background speech or other noise. A task for which the underpinning processes are reasonably well understood in this regard is reading. The recent wave of research on reading (comprehension) processes, as supplemented with eye-tracking measures, may thus offer a way of increasing the use of tasks beyond that of visual-verbal serial recall. A focus on reading may also afford an opportunity to make representation to employers, facility managers and policy makers given the importance of literacy at workplaces and in society in general. While the processes involved in visual-verbal serial recall likely underpin a number of more complex cognitive tasks, such as mental arithmetic, to infer so often requires some analogy that might not be easily grasped by decision-makers. Reading studies may therefore be useful in addressing the long-standing issues in relation to drawing better parallels between tasks undertaken in the laboratory compared to tasks undertaken in real workplace settings. Further, the use of portable eye-tracking measures may offer an opportunity to undertake field studies that are hitherto better matched to laboratory-based studies. And finally, if one dares to look into the future, a standardised test battery for the differential investigation of noise effects on cognitive performance would be highly desirable, from which one can draw as a researcher depending on the specific research intention or as a practitioner depending on the task analysis at the workplace of interest.

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APPENDIX

Please note that the following tables cannot depict the complete information provided in the reports. For example, some applied studies report many different acoustic parameters or applied very extensive questionnaires. In the basic research studies, there is much information on the characteristics of tasks and testing procedures, which might be highly relevant for the obtained results but cannot be presented here. Last but not least, most reports provide much more insights and results than we have been able to condense in these tables. Taken together, the tables presented below do not claim to be complete or free of errors.

Table 1: Overview of Applied Research Studies

Author	**[1] Abbasi et al. (2020)**	**[2] Abdalrahman et al. (2020)**
Sample	35 male university students (mean age 23 years)	university students and staff; Exp. 1: *n* = 28 (13 females; 23-48 years; mean age 31 years); Exp. 2: *n* = 31 (15 females; 24-60 years, mean age 36)
Result	increased noise and air temperature disturbed working memory and neurophysiological responses (combined effect more pronounced than isolated effects); effect of noise on working memory larger than effect of temperature; effect of temperature on neurophysiological responses larger than effect of noise	people prefer water sounds of about 45 dB(A) when played against irrelevant speech of about 48 dB(A); the perception of the sound environment was improved by the introduction of a water feature, and significantly more when adding visual stimuli
Sound quality	simulated low frequency noise in one octave band	irrelevant speech (running speech of one female voice either with added reverberation or with typical office background noise) and six different water masking sounds
Speech intelligibility		Exp. 1: two STI conditions (0.50 and 0.78); Exp. 2: STI = 0.78
Level	two noise levels (55 dB(A) and 75 dB(A))	irrelevant speech: 48 dB(A); water masking sounds: five different SPLs (42, 45, 48, 51, and 54 dB(A))
Office Type		Exp. 1: listening experiment (audio only); Exp. 2: audio-visual preference tests: 3D animations for the visual water features in a picture of an open-plan office
Performance	n-back task	no objective performance measures taken
Task Load	differing workload realised via varied task difficulty	
Annoyance		
Distraction		
Perceived Disturbance		
Additional Information*	Health: neurophysiological responses (EEG, EMG, EGG, EOG, TMP, RSP, GSR, BVP)	Environmental Satisfaction: paired comparisons for sound level preferences (Exp. 1) and audio-visual preferences (Exp. 2); Moderator: presence of visual input

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[3] Acun et al. (2018)**	**[5] Appel-Meulenbroek et al. (2020)**
Sample	49 office employees (26 females)	150 office employees in total from three different Dutch companies; 77% worked in large open-plan offices; 57% females; mean age 41 years
Result	negative interpretation of office soundscape caused by unexpected sounds, sounds out of context, and sounds perceived to interfere with tasks demanding concentration; employees used coping methods like accepting, habituating, intervening with sound source, or wearing headphones	depending on noise source, specific coping strategies were reported more often than others; overall, avoidance coping strategies were chosen most often; personality traits related to coping behavior but not to perception of noise sources.
Sound quality	no presentation of sound recordings, employees from two different offices were interviewed in a meeting rooms	
Speech intelligibility	not measured directly but “reconstructed” via Odeon; STI = 0.52 (engineering office) vs. STI = 0.59 for (architectural office)	
Level	LAeq = 55.3 dB (engineering office) vs. LAeq = 59.4 dB (architectural office)	
Office Type	architectural open-plan office (visual task based) vs. engineering open-plan office (computational task based)	three companies dealing with noise problems (poor acoustics conditions); they all had open-plan office concepts
Performance	no objective performance measures taken	no objective performance measures; questionnaires on effect of variable noise sources, perceived productivity during desk-based focused work (5-point scale), perceived effect of coping strategies on productivity (5-point scale)
Task Load		
Annoyance		
Distraction		
Perceived Disturbance	semi-structured interviews	
Additional Information*	Moderator: context factors: environmental factors, activity, task type; employee characteristics; sound preference, performance	

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[13] Bottenheft et al. (2020)**	**[14] Braat-Eggen et al. (2019)**
Sample	20 participants (from a participant pool; 9 females; 18-55 years, mean age 40)	76 university students (39 females; mean age 25)
Result	no interaction between noise & skipping breakfast (metabolic stressor) on cognitive performance; noise appeared to increase arousal and attention (reflected in higher EDA and P300) in line with higher experienced load and stress; fewer missed 2-back responses in noise condition; maintaining task performance in noise resulted in extra effort	collaboration as a semantic based task was negatively affected by background speech independent of semantic content and reverberation time; perceived disturbance higher when reverberation time was longer, which was interpreted as reflecting increased difficulty of interpersonal communication.
Sound quality	noise bursts (white noise burst; 85 dB at random center frequencies at 1000 Hz, 2000 Hz and 4000 Hz) vs. no-noise bursts	silence (pink noise) vs. two multitalker speech scenarios: mother tongue vs. foreign language; both speech scenarios played-back either with very short vs. very long reverberation time (T = 0.6 s vs. T = 2.3 s); speech binaurally auraziled with room acoustic software
Speech intelligibility		estimated STI = 0.37-0.87
Level	85 dB	control: pink noise at 30 dB(A); speech scenarios: 46.1-60.1 dB(A)
Office Type		open-plan study environments
Performance	2-back task; International Shopping List task	’spot the differences’ task, based on the ’DiapixUK’ pictures collaboration task
Task Load	Rating Scale of Mental Effort (RSME)	
Annoyance		
Distraction		
Perceived Disturbance		7-point Likert Scale
Additional Information*	Health: electrocardiography (ECG), electrodermal activity (EDA), electroencephalography (EEG), blood glucose; Moderator: breakfast vs. no breakfast (metabolic stressor); visual analogue scale on hunger and stress	Mood: 7-point Likert Scale (on eagerness & motivation); Moderator: no moderating effect of noise sensitivity (Weinstein questionnaire)

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[18] Evered et al. (2018)**	**[19] Golmohammadi et al. (2017)**	**[20] Golmohammadi et al. (2021)**
Sample	34 university students (25 females; 19-47 years)	175 employees from 17 different open-space banks	31 male students (25-43 years; mean age 30)
Result	no significant effect of auditory stimulation on different performance measures (signal detection) in an image interpretation test with normal and abnormal cell images.	staff in open bank spaces reported loss of concentration and other aspects of fatigue; staff was highly annoyed by noise, in particular by background speech	all 3 mental effects (annoyance, mental workload, fatigue) affected by neuroticism and noise sensitivity; noise caused less annoyance in individuals with good health; as age increased, so did noise annoyance; introvert individuals felt more mental workload than extrovert individuals
Sound quality	liked music (selected by participants), disliked music (PI selected), speech (audio book, mother tongue), silence	no presentation/variation of sound	five noise conditions: (1) quiet conditions (QC), (2) closed offices (CO), (3) open plan offices (OPO), (3) control rooms(CR), and (4) industrial workplaces (IW)
Speech intelligibility		STI = 0.41 - 0.74	
Level	65-75 dB	Level not reported, but e.g. reverb. time (RT) = 0.45 - 2.45 s; r_D = 8.93 - 26.74 m	noise levels in the five noise conditions: (1) QC: 54 ± 0.6 dB(A), (2) CO: 64 ± 0.4 dB(A); (3) OPO: 68 ± 0.8 dB(A) (4) CR: 73 ± 0.3 dB(A); (5) IW:80 ± 0.1 dB(A)
Office Type		open-space banks	
Performance	image interpretation tests consisted of 30 normal and 30 abnormal cell images	no objective performance measures taken; employees were interviewed	
Task Load			NASA_TLX
Annoyance		100-point noise annoyance scale	numerical rating scale recommended by ISO/TS 15666:2003
Distraction			
Perceived Disturbance			
Additional Information*			Health: General Health Questionnaire (GHQ-28); noise sensitivity questionnaire (Weinstein)

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[21] Haapakangas et al. (2017)**	**[24] Hongisto et al. (2017)**
Sample	883 open-plan office employees	A core group of 18 employees responded to the questionnaire in all conditions (56% females; mean age 38 years)
Result	Noise disturbance by background speech increased with distraction distance (r_D) but no relation to other parameters under consideration	Acoustic satisfaction, subjectively perceived sound quality, subjective distraction and disturbance favoured pseudo-random noise based masking sound over water-based masking sounds
Sound quality	no presentation of sound recordings, employees of 21 different open-space offices were interviewed (in different studies, some have been already published but not all)	office noise superimposed by one out of five masking conditions: artificial sound masking based on pseudo-random noise (PRMS), four different water-based masking sound (WBMS) conditions
Speech intelligibility	r_D = 2.5 - 18.0 m,	r_D (baseline condition): 4 m; $D_{2,S}$ = 7 dB; effects of r_D and $D_{2,S}$ on cognitive performance not analyzed
Level	different measures, e.g. Lp: Lp = 29.0 - 44.5 dB(A); $D_{2,S}$ = 3.3 – 11.0 dB	L_{Aeq} = 43.0 - 44.6 dB(A)
Office Type	open-plan offices (6 or more occupants)	open-plan office
Performance	no objective performance measures were taken	no objective performance measures were taken; perceived performance: 5-point rating scale
Task Load		
Annoyance		5-point rating scale
Distraction		5-point rating scale
Perceived Disturbance	perceived disturbance by noise vs. speech on five-point scales	5-point rating scale
Additional Information*		Job Satisfaction and Environmental Satisfaction: 5-point rating scale

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[27] Jahncke et al. (2020)**	**[29] Kang et al. (2017)**
Sample	113 employees from five offices before relocation (intervention group: *n* = 86, 33 female, mean age 48; control group: *n* = 27, 20 females, mean age 46), and 64 (30 females, mean age 48) out of the 86 employees after shift to activity-based workplaces	231 occupants of university open-plan research offices (86 females; all < 35 years old)
Result	before relocation, performance in shared/open-plan offices worse than in cell offices, while noise level was about 15 dB (L_{Aeq}) higher; after relocation, performance in active zone worse than in all other areas (e.g., shared quiet zones as well as individual working rooms)	among five key aspects of indoor environmental quality, the quality of the acoustic environment had the highest positive correlation with perceived work productivity; satisfaction with acoustic environment largely dependent on perception of quietness
Sound quality	sound recordings at regular office times (occupied) in all office types at baseline; and after relocation	
Speech intelligibility		
Level	Cell rooms: L_{Aeq} = 32 dB(A); shared quiet zone, lounge: L_{Aeq} = 41-45 dB(A); active zone: L_{Aeq} = 49 dB(A)	
Office Type	before relocation traditional offices (open-plan, shared rooms of 2-3 employees, and cell offices) vs. activity-based workplaces after relocation	university open-plan research offices (UOROs)
Performance	serial recall task	no objective performance measure was taken; ratings on office productivity on a 5-point scale
Task Load		
Annoyance		
Distraction		
Perceived Disturbance		level of noise disturbance caused by 10 common noise sources rated on a 5-point scale
Additional Information*		Moderator: age (< 24 years vs. 24-35 years)

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[30] Kang et al. (2019)**	**[34] Keller et al. (2018)**
Sample	38 university students (20 females; 22-27 years; mean age 24)	medical teams involved in 110 surgeries
Result	significant negative effects of speech noise on serial recall performance and subjective ratings on perceived performance, work load, sound disturbance, and acoustic comfort; negative effects increased with increasing STI; subjective ratings more sensitive to different sound conditions than performance measures	self-reported distraction by background noise in operation rooms during open abdominal surgeries varied over three phases (opening, main phase, closing) and with regard to different surgical teams
Sound quality	5 acoustic conditions: (1) no masker and no speech noise, (2) no masker and speech noise (STI = 0.67), (3) masker and no speech noise, (4) masker and speech noise with STI = 0.32, (5) masker and speech noise with STI = 0.5	
Speech intelligibility	different SNR resulting in different STI values: STI = 0.32 - 0.67	
Level	pink noise as masking sound: SPL = 40.4 dB(A); speech: SPL = 39.5 - 45.9 dB(A)	L_{50} = 53.79 - 56.85 dB(A)
Office Type	open-plan office environment simulated in a laboratory	operation rooms
Performance	serial recall, mental arithmetic, reading comprehension, proofreading; subjective performance rated on a 5-point scale	no objective performance measures were taken
Task Load	work load on a 5-point scale	difficulty of surgery on a 7-point scale
Annoyance		
Distraction		perceived distraction on a bipolar 7-point scale
Perceived Disturbance	5-point scale	
Additional Information*	Acoustic Comfort on a 5-point scale	Moderator: surgery phase and role in the surgical team

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[38] Lee et al. (2020)**	**[39] Lenne et al. (2020)**
Sample	16 employees of a pharmaceutical company (4 females)	90 employees
Result	discrepancy between subjective preference of soundscapes and performance; no significant effect of noise conditions on performance; typical office noise without masker at least satisfactory for cognitive performance; lowest preference ratings for spring water sound masker	long-term field study revealed no positive effects of a sound masking system on assessed psychological factors; noise annoyance even increased
Sound quality	no office noise vs. typical daily office noise vs. two masker conditions: white noise or spring water sound superimposed on typical daily office noise	broadband noise emitted by a sound masking system; diffuse sound field
Speech intelligibility		
Level	60 dB(A) for office noise; 44–45 dB(A) for soundscaping (white noise and springwater sound)	automatically adapted to sound level of office activities
Office Type	meeting room was used to simulate a typical large open-plan office in a pharmaceutical company	open-plan office
Performance	three tasks: Flanker task, Shape N-back task and Stroop task; perceived satisfaction with performance on bipolar 7-point scale	no objective performance measures were taken; perceived performance on 5-point Likert scale (Multidimensional Fatigue Inventory)
Task Load		8-point Likert scale (questionnaire)
Annoyance		5-point Likert scale (GABO questionnaire)
Distraction		
Perceived Disturbance	bipolar 7-point scale	
Additional Information*	Health: blood pressure; pulse oximeter; EDA sensor; Environmental Satisfaction: rating on willingness to hear a masking sound for a full working day on bipolare 7-point scale	Job Satisfaction: 5-point Likert scale (Multidimensional Fatigue Inventory); Environmental Satisfaction: 5-point Likert scale (GABO questionnaire)

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[40] Lou et al. (2020)**	**[42] Ma et al. (2018)**
Sample	20 participants (22-27 years, mean age 25)	75 university students (mean age 25 years)
Result	detrimental impact of background speech on reading performance depended on STI of background speech; with higher STI, reading performance and perceived acoustic comfort decreased, while perceived disturbance increased	soundscape elements perceived as pleasant had a positive effect on tiredness restoration and annoyance reduction; sound elements had a greater effect on psychological restoration compared with visual scenes; continuous sound did not have better restorative effects than intermittent sound
Sound quality	background speech (Chinese = mother tongue) during masking sound (pink noise) with different signal-to-noise ratios (SNR) resulting in 5 conditions with different STI	(a) different sound types (pilot study on preferences): flowing water sound, birdsong, footsteps, traffic noise, air-conditioner noise; (b) different sound sequences; (c) different audio-visual conditions (photos of different open-plan offices)
Speech intelligibility	STI = 0.08 - 0.78	
Level	SPL = 50 dB(A) for all five sound conditions	all sound scenarios presented at 55 dB(A)
Office Type	laboratory was used to simulate a common mid- or large-sized open-plan office	simulated open-plan office
Performance	reading comprehension (accuracy) measured with ESLR material (english texts for Chinese participants)	visual search: find a target figure from many similar figures
Task Load	perceived performance on 5-point scale	
Annoyance		7-point Likert-type scales
Distraction		
Perceived Disturbance	5-point scale	
Additional Information*	Environmental Satisfaction: acoustic comfort on 5-point scale	

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[54] Polewczyk et al. (2020)**	**[71] van Hedger et al. (2019)**
Sample	44 teachers and 378 students (second to eighth grade)**	63 participants (35 females; 18-44 years; mean age 21)
Result	teachers reported a significant improvement regarding their work with students (e.g., better understanding of verbal instructions) and in their own work conditions (e.g., overall comfort of work, reduced voice effort) after the acoustic treatment of a school	performance assessed before and after exposure to natural or urban soundscapes; significant improvements in cognitive performance for individuals exposed to natural soundscapes; urban soundscapes did not systematically affect performance
Sound quality		40 natural and 40 urban soundscapes
Speech intelligibility		
Level		average loudness of the soundscapes (root-mean-sqare) 70 dB SPL
Office Type	Acoustically treated school	
Performance	no objective measures taken; teacher version of the Acoustic Change Feelings Scale (ACFS-T)	directed attention: composite performance of backward digit span task and a dual n-back task
Task Load		
Annoyance		
Distraction		
Perceived Disturbance		
Additional Information*		Mood: affective questionnaire pre and post intervention (PANAS) and aesthetic judgements of soundscapes (three-point scale)

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator
**Children were not considered in this overview

Author	**[76] Yadav et al. (2019)**	**[78] Zhang et al. (2021)**
Sample	Exp. 1: *n* = 60 (31 females; 18-55 years; mean age 25); Exp. 2: *n* = 62 (31 females; 18-55 years; mean age 26)	30 university students (15 females; 18-27 years; mean age 22)
Result	Exp. 1: increasing the number of talkers from 0 to 1 and from 1 to 2 resulted in statistically significant decline in visual-verbal serial recall performance; in the writing task, pauses between words increased significantly from 1 to 2 simultaneous talkers; Exp. 2: cognitive performance remained largely unchanged between 45 to 57 dB	type of masking sound and signal-to-noise ratio (SNR) affected objective performance, subjective workload, perceived disturbance and acoustic satisfaction; spring water sound resulted in best objective performance when presented at a high SNR, and in highest acoustic satisfaction when presented at medium SNR
Sound quality	acoustic simulation of realistic multi-talker speech from spatially separated talkers. For Exp. 2, a range of gain values were used (45-57 dB).	quiet vs. speech only vs. 12 masking sound conditions in which different maskers at different SNR were superimposed on speech
Speech intelligibility		four masking sounds (speech-like pink noise, air-conditioning noise, spring water sound, speech babble), each given under three levels of SNR levels (2.3 dB - 6.6 dB)
Level		~55 dB(A)
Office Type	climate-controlled chamber that was set-up as a medium-sized open-plan office.	laboratory room simulating an open-plan office
Performance	cognitive tasks: visual-verbal (digit) serial recall task, and a writing task	visual-verbal serial recall
Task Load		NASA-TLX
Annoyance		
Distraction		
Perceived Disturbance		5-point rating scale
Additional Information*	Moderator: number of talkers	Environmental Satisfaction: acoustic satisfaction on 5-point rating scale; Moderator: educational level (under- vs. post-graduate), gender, noise sensitivity (Weinstein scale)

*Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Table 2: Overview of Basic Research Studies

Author	**[4] Antonietti et al. (2018)**	**[6] Ball et al. (2018)**	**[7] Barker et al. (2019)**
Sample	university students; Exp. 1 + 2: *n* = 24 (23 females; 19-31 years; mean age 23); Exp. 3: *n* = 24 (22 females; 19-24 years; mean age 22); Exp. 4: *n* = 24 (21 females; 19-42 years; mean age 25)	Exp. 1: 64 participants (36 females; 18-49 years; mean age 27); Exp. 2: 68 participants (41 females; 18-45 years; mean age 25)	Exp. 1: 179 university students; Exp. 2: 60 participants (53 females; mean age 23)
Result	while effect of irrelevant pure-tones varied with intervallic organisation (i.e., random sound sequences impeded recall, whereas ascending sound sequences or repeated sounds did not), this effect was not observed in the case of irrelevant piano-note sequences; with random anisynchrony (i.e., random temporal variation), neither piano notes nor pure tones caused disruption	Exp. 1: an intrinsic metacognitive cue in form of processing disfluency (manipulated using an easy-to-read vs. difficult-to-read font) mitigated detrimental impact of auditory distraction on solution rates for CRATs; Exp. 2: an extrinsic metacognitive cue that took the form of an incentive for good task performance (i.e., 80% or better CRAT solutions) eliminated the negative impact of distraction on CRAT solution rates	Exp. 1: robust effect of irrelevant speech on visual-verbal serial recall; effect size not influenced by talker familiarity; Exp. 2: still no effect of familiarity after four 30-min training sessions in which participants were familiarised with the talker
Sound quality	Exp. 1: silence vs. piano notes (steady-state vs. ascending vs. random sound sequences); Exp. 2: same as Exp. 1 but pure tones; Exp. 3: same as Exp. 1 but different timing; Exp. 4: same as Exp. 3 but with pure tones from Exp. 2	irrelevant speech (spoken from a transcript of a story) vs. quiet	silence vs. speech (from Revised List of Phonetically Balanced Sentences: Harvard Sentences); participants were either familiar with the talker (a female course instructor) or not; they were either informed that they were or were not familiar with the talker
Speech intelligibility			
Level		~60-65 dB(A)	comfortable listening level (Exp. 1); maximum comfort level (Exp. 2)
Office Type			
Performance	visual-verbal serial recall task	Compound Remote Association Tasks (CRATs)	Exp. 1: visual-verbal serial recall task; Exp. 2: pre- & post-training VSR task
Additional Information*		Moderator: Exp. 1: easy/hard-to-read font;	Moderator: Exp. 1: talker familiarity; Exp. 2: talker training (controlled exposure to the talkers voice)

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[8] Bell et al. (2017)**	**[9] Bell et al. (2019a)**
Sample	pilot study: 92 university students (66 females, mean age 24 years); replication 1: 162 German university students (127 females; mean age 23 years); replication 2: 88 Swedish university students (41 females; mean age 27 years)	Exp. 1: 103 participants (74 females, man age 23 years); Exp. 2: 106 participants (70 females, mean age 24 years)
Result	pilot study: visual-verbal serial recall more distracted by sequences of changing, as compared with non-changing (steady-state) monosyllabic word distracters; disruption from sentential distracters (complex changing-state sequences) greater compared to sequences of changing and repeated monosyllabic words; sequences with an unexpected item (e.g., different monosyllabic word among repeated monosyllabic word) produced disruption relative to repeated word (steady-state) condition; foreknowledge only reduced disruption produced by sentential distracters (complex changing-state); effect of foreknowledge on the complex changing-state condition significant in both replication studies, but the critical interaction between foreknowledge and distracter type attained statistical significance only when the data of both replication studies were combined	face recognition impaired by irrelevant speech relative to quiet; changing-state (sentential) speech disrupted performance more than steady-state (repeated word) speech, which in turn produced disruption compared with quiet; results were replicated in a second study wherein the speech was reversed; suggests that the disruptive potential of background speech on face recognition does not depend on its semantic content
Sound quality	steady state (repeated one syllable word), deviation (like steady state but with one deviant distracter), simple changing state (8 different one-syllable words), complex changing state (coherent sentences)	Exp. 1: changing-state (sentential speech) vs. steady-state (repeated monosyllabic word) vs. silence; Exp. 2: same as Exp. 1 but sound files were reversed
Speech intelligibility		
Level	binaurally at approximately 65 dB(A)	65 dB(A)
Office Type		
Performance	serial recall performance (strict serial recall criterion)	face recognition (faces from FERET database)
Additional Information*	Moderator: with or without foreknowledge (the to be ignored sequence was visually presented in advance)	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[10] Bell et al. (2019b)**	**[11] Bell et al. (2019c)**	**[12] Bell et al. (2019d)**
Sample	273 participants (199 females, mean age 22 years)	university students; Exp. 1: *n* = 162 (114 females, 18-38 years, median age 21); Exp. 2: *n* = 419 (313 females, 17-40 years, median age 22)	university students; Exp. 1: *n* = 130 (108 females, 17-41 years, mean age 21); Exp. 2: *n* = 139 (106 females, 17-50 years, mean age 23)
Result	sequences of changing items (monosyllabic words; changing-state) produced more disruption than a repeated monosyllabic word (steady-state) - the changing-state effect; sequences comprising a single change to a repeated monosyllabic word (deviant) produced more disruption than a sequence of repeated single words - the auditory deviant effect; results were comparable across two testing sessions; neither changing-state effect nor auditory deviant effect correlated significantly with any of the personality traits measured (Eysenck personality questionnaire EPQ-R)	visual-verbal serial recall was disrupted by steady-state distracters; "steady-state" effect significantly reduced after pre-exposure to repeated distracter item, which was either a one-syllable word (Exp. 1) or an instrumental sound (Exp. 2)	disruption increased not only when distracter token set size increased from 1 to 2, but also when it increased from 2 to 8 one-syllable words (Exp. 1) and brief instrumental sounds (Exp. 2); findings are interpreted to be inconsistent with the duplex-mechanism account and support the attentional account
Sound quality	steady state condition (repeated one-syllable word) vs. auditory deviant condition (steady state sequence was interrupted by one deviant one-syllable word) vs. changing state condition (ten different one-syllable words)	quiet-condition vs. steady-state condition (one-syllable word repeated during pre-exposure interval and memorization interval) vs. quiet-steady condition (no distracter during pre-exposure, but during memorization interval); Exp. 2: same as Exp. 1, but with instrumental sounds instead of one-syllable words	Exp. 1: zero-token (quiet) vs. one-token (steady-state = 1 one-syllable word) vs. two-token (2 one-syllable words) vs. eight-token condition; Exp. 2: same as Exp. 1 but instrumental sounds instead of one-syllable words
Speech intelligibility			
Level	65 dB(A)	65 dB(A)	65 dB(A)
Office Type			
Performance	visual-verbal serial recall	visual-verbal serial recall	visual-verbal serial recall
Additional Information*		Moderator: exposure to distracter sequence	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[15] Defilippi et al. (2019)**	**[16] Dorsi et al. (2018)**	**[17] Elliott et al. (2020)**
Sample	22 university students with little or no musical training (mean age 26 years) and 21 professional musicians (mean age 30 years)	university students; Exp. 1: n = 81; Exp. 2: n = 77; Exp. 3: n = 77	university students; Exp. 1: n = 102 students (81 females; 18-36 years; mean age 20); Exp. 2: n = 80 (18-36 years; mean age 20)
Result	presence of irrelevant tones (but not words) significantly impeded tone recognition; pseudoword recognition was neither disrupted by irrelevant tones nor words; musicians better in tone (but not pseudoword) recognition than participants with little or no musical training	noise-vocoded speech resulted in the Irrelevant Sound Effect; the greater the number of noise channels (i.e., greater signal complexity), the more impaired recall performance; speech-like noise-vocoded speech (i.e., greater speech fidelity) resulted in a more pronounced Irrelevant Sound Effect than selectively reversed noise-vocoded speech; while, in the missing item task, noise-vocoded speech lowered performance compared to the silent control, this effect did not depend on signal complexity and speech fidelity	Did not replicate prior work by Macken, Phelps, and Jones (2009)[1], in which the size of the Irrelevant Sound Effect was not significantly related to a type of auditory processing called global pattern matching.
Sound quality	silence vs. irrelevant tones (six tones during retention interval) vs. irrelevant speech (disyllabic words during retention interval)	Exp. 1: Noise-vocoded speech, varying in the number of channels (3, 6, 9, and 12) vs. white noise (control); Exp. 2+3: Noise-vocoded speech vs. selectively-reversed noise-vocoded speech vs. silence (control)	the same sounds files were used as in Macken et al. (2009)[1]; tones spanning the octave. Starting at 250 Hz, these were divided into seven equally-spaced logarithmic steps.
Speech intelligibility			
Level		70 dB	
Office Type			
Performance	tonal sequence recognition (2 sequences; 7 sine tones each); phonological sequence recall (sequence of pseudowords); tonal and phonological recognition in the presence of irrelevant sounds (silence vs. irrelevant tones vs. irrelevant speech)	Exp. 1: visual recall task; Exp. 2: visual recall task; Exp. 3: missing item task	Exp. 1: 3 Working-memory capacity tasks (operation span, symmetry span, rotation span); Raven's advanced progressive matrices; Attention control task (antisaccade task); Auditory sequencing tasks; Visual-verbal serial recall task (digits); Exp. 2: Auditory sequencing task and visual-verbal serial recall task
Additional Information*	Moderator: musicians vs. non-musicians		

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

[1] Macken, W. J., Phelps, F. G., & Jones, D. M. (2009). What causes auditory distraction?. *Psychonomic Bulletin & Review*, *16*(1), 139–144.

Author	**[22] Hanczakowski et al. (2017)**	**[23] Hanczakowski et al. (2018)**
Sample	university students; Exp. 1: *n* = 23; Exp. 2: *n* = 20; Exp. 3: *n* = 42; Exp. 4: *n* = 44; Exp. 5: *n* = 28; Exp. 6: *n* = 19	university students; Exp. 1: *n* = 30; Exp. 2: *n* = 30; Exp. 3: *n* = 29; Exp. 4: *n* = 30; Exp. 5: *n* = 56; Exp. 6: *n* = 21; Exp. 7: *n* = 23; Exp. 8: *n* = 34
Result	disruptive effect of semantic similarity between visual memoranda and auditory distracters was reversed when distracters were semantically related to studied visual lists, and when category-cued recall tests were provided during retrieval; Participants' judgements of their learning of category-items were higher when related distracters accompanied the to-be-remembered visual items	presence of background speech disrupted free recall; participants' judgements of learning for visual words accompanied by background speech showed that they were aware of the disruption; given opportunity, participants did not adjust study time to compensate for these effects; therefore, this background-speech induced disruption was more pronounced as compared with presentation rates imposed by the researchers; evidence is provided that the presence of distracter during encoding disrupts time perception rather than disrupting a deliberate strategy
Sound quality	Exp. 1: quiet vs. related auditory distracter vs. unrelated auditory distracter (females speaker); Exp. 2 - 6: related vs. unrelated auditory distracters (females speaker)	semantic category-exemplars
Speech intelligibility		
Level		
Office Type		
Performance	category-cued recall and judgements of learning	free recall and judgements of learning
Additional Information*	Moderator: semantic relationship between visual memoranda and to-be-ignored speech.	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[25] Hughes et al. (2020)**	**[26] Jagadeesh et al. (2019)**
Sample	university students; Exp. 1: *n* = 28; Exp. 2: *n* = 62 (25 who used a serial rehearsal strategy and 37 who did not)	24 normal-hearing native speakers (14 females; 18-25 years; mean age 21)
Result	Exp. 1: opportunity to predict (forewarning) contents of an imminent spoken distracter reduced its disruptive effect, but this was only observed for complex changing-state sequences (meaningful sentences) and the level of disruption produced by simple changing-state sequences; unpredictable simple changing-state sequences were as disruptive as predictable simple changing-state sequences; Exp. 2: disruptive effect of complex changing-state sequences observed in the missing-item task and occurred regardless of whether participants self-reported using serial rehearsal; however, foreknowledge reduced disruptive effect of complex changing-state sequences to the level observed from the simple changing-state sequences; disruption produced by simple changing-state sequences as compared with steady-state sequences was not modulated by foreknowledge and manifest only for participants who self-reported using a rehearsal strategy	a masker containing lexical-semantic information (2SB) produced the greatest disruption to WM scores on a backward digit span task; maskers containing acoustic-phonetic information (8SB and RBs) produce a significantly smaller amount of disruption and speech spectrum noise (energetic masking) was not significantly disrupting as compared with a quiet control condition
Sound quality	Exp. 1: steady-state sequence vs. unpredictable simple changing-state sequence [letters] vs. predictable simple changing-state sequence [letters] vs. complex changing-state sequence [meaningful sentences]; Exp. 2: steady-state sequence vs. simple changing-state sequences vs. complex changing-state sequences	six background conditions: (1) quiet, (2 & 3) 2- and 8-speaker babbles (2SB and 8SB), (4 & 5) time-reversed 2- and 8- speaker babbles (2RB and 8RB), (6) speech spectrum noise
Speech intelligibility		
Level	~65 dB(A)	
Office Type		
Performance	serial recall task and missing-item task	backward digit span
Additional Information*	Moderator: task strategy (serial rehearsal); foreknowledge	Moderator: informational masking

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[28] Joseph et al. (2018)**	**[31] Kattner et al. (2018)**	**[32] Kattner et al. (2020a)**
Sample	89 children (47 girls; 7-9 years; mean age 8) and 89 university students (69 females; 18-22 years; mean age 20)	Exp. 1: 40 participants (19 females; 19-67 years; mean age 32); Exp. 2: 51 participants (37 females; 20-40 years; mean age 26)	75 participants (55 females; 18-31 years, mean age 22)
Result	disruption produced by sequences of changing-items compared to sequences of repeated items (the changing-state effect) was found for children and adults; disruption by an unexpected sound (a deviant) was stronger for children than for adults	performance was affected by the prosody (emotional intonation), but not by the semantics (word meaning), of irrelevant speech; Exp. 2: dissociation between disruptive effects of continuous speech and speech with sudden acoustical deviations on serial and nonserial verbal STM tasks	interference produced by task-irrelevant speech could be reduced through an extensive dichotic-listening training (training of auditory selective attention)
Sound quality	steady-state irrelevant sound repeated speech token) vs. changing-state (two alternating speech tokens) vs. changing-state with deviant token (male voice token within otherwise females voice changing-state sequence) vs. steady-state with deviant item vs. silence	independent variable 1: different emotional semantics (neutral, positive, negative) (from Berlin Affective Word list); independent variable 2: emotional intonation (prosody) (intonated neutrally, exaggerated angry or exaggerated happy) + gaussian noise as control condition; Exp. 1: irrelevant words presented during serial recall varied; Exp. 2: full sentences varied in emotional semantics and intonation + prosodic deviation of single word within neutral sentences	three types of irrelevant sound (female speech, male speech, and noise); recordings of arbitrary excerpts from German textbooks (and thus meaningful to the participants).
Speech intelligibility			
Level	~55 dB(A)	mean SPL of 65.7 dB Gaussian noise was played as a non-speech control condition at 63 dB SPL	72 dB(A)
Office Type			
Performance	1. digit span task (to assess short-term memory capacity); 2. serial recall task; 3. probed-order recall task; 4. missing-item task	Exp. 1: serial recall task; Exp. 2: serial recall task + missing item identification	pretest and posttest: visual and auditory serial recall
Additional Information*	Moderator: age	Moderator: demands of the focal task	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[33] Kattner et al. (2020b)**	**[35] Körner et al. (2017)**	**[36] Körner et al. (2019)**
Sample	50 participants (37 females; 27 non-musicians aged 18-55 years, mean age 26; 23 musicians aged 18-39 years, mean age 23)	university students; Exp. 1: *n* = 138 (95 females; mean age 24 years); Exp. 2: *n* = 63 (42 females; mean age 25 years); Exp. 3: *n* = 142 (110 females; mean age 22 years)	university students; Exp. 1a: *n* = 90 (63 females; 19-40 years; mean age 26); Exp. 1b: *n* = 79 (47 females; 18-45 years; mean age 26); Exp. 2a: *n* = 102 (67 females; 19-39 years; mean age 24); Exp. 2b: *n* = 123 (83 females; 18-39 years; mean age 23)
Result	irrelevant instrumental music was found to produce more disruption of tonal recall than white noise, whereas irrelevant speech produced intermediate levels of disruption (independent of musical expertise); participants with musical expertise were generally better at recalling tones; conclusion was that different mechanism exists for memorizing tonal and phonological input	working memory capacity was unrelated both to the size of the changing-state effect and to the size of the deviation effect (for simple as well as complex stimuli); additionally, in Exp. 2, frequency of changing-state or deviation sequences within each block did not modulate auditory distraction at all; findings challenge idea that there are two fundamentally different mechanisms of auditory distraction	changing-state and deviant distracter sounds interfered with both encoding and retention of the targets: changing-state effect and deviation effect are parallel in how they vary as a function of the time of distraction
Sound quality	to-be-remembered tones: three different sine tones with frequencies of 261.6 Hz (C4,“low”), 293.7 Hz (D4, “medium”), and 329.6 Hz (E4, “high”); irrelevant sounds: classical instrumental music vs. speech in unknown language vs. white noise	changing-state (German sentences) vs. steady-state sequences (repeated monosyllabic word); deviation block (repeated monosyllabic word with deviant monosyllabic word in between)	steady-state vs changing-state (Exp. 1a); sentential speech (Exp. 1b); deviant distracter words added (Exp. 2a); time of distraction (4 different timing conditions)
Speech intelligibility			
Level	to-be-remembered sounds: SPL of 72 dB; irrelevant sounds: 66 dB	auditory distracter sequences: average sound level of 60 dB(A) L_{eq}	~55 dB(A)
Office Type			
Performance	tonal serial recall vs. verbal serial recall	operation span task; sentence span task; standard serial recall task	serial recall
Additional Information*			

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[37] Kreitewolf et al. (2019)**	**[41] Lu et al. (2020)**	**[43] Marois et al. (2019)**
Sample	66 university students (59 females, 17-48 years) and 20 family members or close friends of two individuals providing voice recordings	22 college students (mean age 22 years)	34 university students (19 females; mean age 26 years)
Result	familiarity with the voice conveying auditory distracter sentences during retention of memoranda led to lower performance for students who were familiar vs. unfamiliar with the speaker's voice (having been taught by them), although this was not observed for a sample who were family members or friends of one of the speakers; disruption produced by familiar against unfamiliar speakers was evident even when participants expected to hear a sentence spoken by a familiar speaker that was not presented; degree of familiarity appears to moderate effect of speaker familiarity on working memory disruption	colour noises improved participants' cognitive performance; in the Psychomotor Speed Test, response times were longest in the presence of background noise only, compared to any colour noise; performance in the Continuous Performance Test was better in the pink noise condition than in background noise only; in the Executive Function Test, participants were significantly faster in the presence of colour noise (particularly red noise) than in background noise only; in the Working Memory Test, red and pink noise resulted in significantly better performance levels than background noise only	the physiological index of attention orienting, the pupillary dilation response (PDR) occurred to an unexpected deviant sound (pink noise) in a sequence of changing letters but not to a letter-to-letter change per se; this underlines the (unitary) view that both deviants and letter-to-letter changes produce attentional capture and supports a (duplex) view that deviants produce attentional capture whereas acoustic changes produce an interference-by-process
Sound quality	German version of speech-in-noise sentences spoken by two different speakers	masking sounds: red noise vs. pink noise vs. white noise vs. background noise only	pink noise burst, letters
Speech intelligibility			
Level	participants adjusted loudness to comfortable levels	masking sounds: 47 dB(A) for colour noises (red, pink, and white noise), and 44 dB(A) for background noise only	not included
Office Type			
Performance	auditory-verbal serial recall	Psychomotor Speed Test, Continuous Performance Test (Identical Pairs), Executive Function Test (Trail Making), and Working Memory Test (odd-even number sequencing)	visual-verbal serial recall
Additional Information*	Moderator: Degree of familiarity with the speaker.	Environmental Satisfaction: questionnaire on acoustic comfort	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[44] Marsh et al. (2018a)**	**[45] Marsh et al. (2018b)**	**[46] Marsh et al. (2020)**
Sample	university students; Exp. 1: *n* = 76 (between-participants; 17-20 years, mean age 19); Exp. 2: *n* = 76 (between-participants; 18-47; mean age 21)	university students: Exp. 1: *n* = 134 (18-54 years); Exp. 2: *n* = 6 (18-41 years)	university students; Exp. 1: *n* = 60 (between-participants); Exp. 2: *n* = 30 (within-participant)
Result	ignoring one half of a conversation (e.g., one speaker) resulted in poorer performance than ignoring both halves (e.g., both speakers); this 'halfalogue' effect only manifested when participants could comprehend the meaning of the speech and was abolished when the task-engagement was greater when the focal task materials were presented in a disfluent font	post-categorical auditory distraction in serial short-term memory is functionally unrelated to the classical irrelevant speech effect; valent words produced greater disruption than neutral words regardless of whether the focal task required serial recall (the missing-item task was adopted in Exp. 2); the disruption produced by valent words was modulated by increasing task-engagement (Exp. 1); the disruption produced by speech per se (neutral auditory distracters) was attenuated for the missing-item task (Exp. 2) as compared with the serial recall task (Exp. 1)	participants were presented with hierarchical stimuli, Navon letters, for recall wherein a large letter comprises a number of smaller letters of a different identity. Participants were either requested to attend and recall the small letters making up large letters (high encoding load), or recall the large letters (low encoding load); high encoding load eliminated disruptive effect of an unexpected auditory deviant (white noise) within a sequence of repeated tones, but failed to ameliorate the disruption produced by a changing sequence of tones
Sound quality	conversational speech, spectrally-rotated speech.	irrelevant speech vs. quiet; different emotional valence (positive vs. negative vs. neutral)	pink noise burst, sine-wave tonesE4)
Speech intelligibility			
Level	~69 dB(A) L_{eq}	65 dB(A)	~65 dB(A)
Office Type			
Performance	search task for statistical information in tabulated form	serial recall (Exp. 1); missing-item task (Exp. 2)	visual-verbal serial recall
Additional Information*	Moderator: high task-difficulty moderated the disruption produced by the (meaningful) halfalogue, i.e. task load as moderator	Task Load: task-encoding load (Exp. 1); focal task process (Exp. 2)	Task Load as moderator: high perceptual load moderated the deviation but not the changing-state effect

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[47] Marsh et al. (2021)**	**[48] Meng et al. (2020)**	**[49] Molesworth et al. (2018)**
Sample	university students; Exp. 1: *n* = 48 (34 females; mean age 24 years); Exp. 2: *n* = 36 (18 females; mean age 24 years); Exp. 3: *n* = 30 (20 females; mean age 23 years)	60 university students (52 females, mean age 23 years); Chinese-speaking; between-participants design with 30 in each group)	40 participants (half non-native English speakers; 21 females; mean age 22 years)
Result	sequence of different letters (Exp. 1) and tones (Exp. 2) as compared to repeated tokens produced greater disruption to creative task performance; speech that was meaningful to participants produced an additional disruptive effect; conclusion was that changing-state sounds disrupt solution-evaluation processes (involving inner speech planning) whereas the semanticity of speech impacts on solution-generation processes	meaningful speech produced more disruption of Chinese reading than meaningless speech when the reading task required judgement of whether a sentence made sense, but not when participants were required to search for a non-character; the presence of meaningful against meaningless speech and quiet increased numbers of fixations, regressions, regression path and total reading times; disruption by the meaning of task-irrelevant speech depends on both the nature of the sound and the task-process deployed	working memory and recognition memory were immune from the effects of babble at either 55 or 65 dB(A); recognition memory (cued recall) was found to be vulnerable to the effects of broadband noise at 65 dB(A) but not at 55 dB(A); in the most extreme case, broadband noise adversely affected recognition memory by 15%
Sound quality	sequence of letters (repeated or different); sequence of tones, alternating or repeated [A4 [440 Hz] and E4 [329.628 Hz]; concatenated meaningful sentences or meaningless sentences (spectrally-rotated)	Chinese speech and Uyghur speech	babble (multi-talker incomprehensible speech) vs broadband noise (similar to services and machinery noise)
Speech intelligibility			
Level	65-70 dB(A)	58-70 dB(A)	55 vs. 65 dB(A) vs. no noise (38-40 dB(A) L_{eq}
Office Type			
Performance	compound remote associates test; self-report of solution	eye-tracking measures; identify non-character; sentence acceptability decision	working memory tests (linguistics, grammatical reasoning and mathematics); recognition memory test (cued recall)
Additional Information*	Moderator: changing vs. steady state properties of background sound and its meaning	Moderator: task process	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[50] Molesworth et al. (2020)**	**[51] Monteiro et al. (2018)**	**[52] Muhammad et al. (2019)**
Sample	66 university students (34 females; mean age 23 years)	15 female university students (20-23 years; mean age 22)	20 students (6 females; 21-37 years; median age 26)
Result	both babble and broadband noise induced learned helplessness; when it was possible to escape from noise, by finding certain combinations of keys (e.g., up and right arrows), the type of noise also affected performance, with babble noise adversely affecting individuals' ability to escape more than broadband noise	participants' performance during the tests was lower in the loudest condition (C3), that is, the number of errors was higher and the reaction time longer; participants also experienced higher levels of discomfort, stress, and annoyance perceptions in this condition; however, task performance was not found to be influenced by these perceptions	patterns of disruption from task-irrelevant sounds on visual-verbal serial short-term memory and subjective ratings in VR experiment were the same as those measured in a real and audio-only laboratory setting; background speech of high intelligibility produced more disruption than that of lower intelligibility that produced disruption relative to the control condition
Sound quality	noise (babble vs. broadband vs. quiet)	standard condition vs. environmental noise (fast-food restaurant sounds) without alarm sounds vs. environmental noise with alarm sounds (1000 Hz)	semantically meaningful speech vs. silence condition (very soft pink noise)
Speech intelligibility			soft speech signal of good intelligibility vs. bad intelligibility
Level	75 dB(A) L_{eq} for both types of noise; ambient noise level 38 dB(A) L_{eq} for silent condition	noise levels were fixed at 45 ± 0.3 dB(A) (C1), 60 ± 0.4 dB(A) (C2), and 68 ± 0.4 dB(A) (C3)	
Office Type			office rendered in VR vs. standard lab setting
Performance	questionnaire with 10-cm-line between two anchor points (perceived annoyance, pleasantness, and perceived performance); participants required to find correct combination of keys to silence noise (when possible to escape noise); time taken to give-up	attention and short-term memory: serial recall, response inhibition, and Stroop interference	visual verbal serial recall task
Additional Information*	Annoyance: questionnaire with 10-cm-line between two anchor points; unpleasantness of noise: questionnaire with 10-cm-line between two anchor points	Annoyance: visual analog scales; stress: visual analog scales; discomfort: visual analog scales; mood: Depression, Anxiety and Stress Scales (DASS-21)	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[53] Othman et al. (2019)**	**[55] Renz et al. (2018a)**	**[56] Renz et al. (2018b)** **[57] Renz et al. (2018c)**
Sample	20 male participants (18-24 years; mean age 21)	Exp. 1: 24 participants (6 females; 19-68 years; median age 26); Exp. 2: 31 participants (12 females; 21-34 years; median age 23)	24 students (6 females; 20-29 years; median age 24)
Result	Auditory working memory performance was significantly enhanced in 10 and 5 dB signal-to-noise ratio (SNR).	in Exp 1., there was no difference between different masking sounds (-3 dB signal-to-noise ratio) regarding objective performance measures and annoyance ratings; in Exp. 2, however, higher signal-to-noise ratio (SNR) between masker and to-be-masked speech were realised, resulting in significant differences between masked conditions: babble masking improved cognitive performance in dependency of its SNR and similarly to broadband noise, but was perceived as more annoying	(2018b): In comparison to a steady-state masking sound, time-reversed speech is a more efficient masker for background speech, yet it is not more effective for reducing detrimental effects of background speech on objective cognitive performance and is even perceived as more annoying; (2018c): beneficial effects of a masker on objective performance were dependent on its frequency spectrum at certain signal-to-noise ratios (SNRs); subjective annoyance ratings were dependent on SNR but did not vary between the two tested maskers of differing frequency spectra
Sound quality	target speech (bi-syllabic words) (meaningful but unrelated), white noise	Exp. 1: quiet vs. dry recording of unmasked speech vs. 10 masked speech conditions: maskers were babble sounds (12 vs. 48 voices, only female vs. only male voices), waterfall sound, continuous noise with speech spectrum, wind sound, time reversed speech; Exp. 2: quiet vs. dry recording of unmasked speech vs. 8 masked speech conditions (continuous noise and voice babble of differing spectra both varied in SNR)	quiet vs. speech vs. 12 masking sound conditions; (2018b): analysis on a time-reversed masker in 3 different SNRs are presented; (2018c): analysis on 9 masking sound conditions is reported in which two maskers of different frequency spectra were superimposed on the speech signal in different SNR
Speech intelligibility		Exp 1: STI = 0.38 - 0.46 in the masker conditions; Exp 2: STI = 0.16 - 0.33 in the masker conditions	
Level	targeted-speech: 60 dB SPL; white noise: 45-60 dB SPL at SNR of 15 dB, 10 dB, 5 dB and 0 dB	masking sounds: SPL = 45 dB(A); speech: SPL = 42 dB(A)	masking sounds: SPL = 45 dB(A); speech: SPL = 33 - 42 dB(A)
Office Type			
Performance	auditory word-based backward recall task	visual-verbal serial recall	visual-verbal serial recall
Additional Information*		Annoyance: 5-point Likert scale and 11-point scale	Annoyance: 5-point scale and 11-point scale

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[58] Renz et al. (2018d)**	**[59] Renz et al. (2018e)**	**[60] Röer et al. (2017a)**
Sample	25 employees (6 females; 21-65 years; median = 38)	24 participants (12 females), 20-65 years (median=24)	university students; Exp. 1: *n* = 60 (40 women; mean age 24 years); Exp. 2: *n* = 74 (50 women; mean age 24 years) ; Exp. 3: *n* = 82 (58 women; mean age 25); Exp. 4: *n* = 84 (64 women; mean age 24)
Result	beneficial effects of a masker on objective performance and subjective annoyance varied with the spatial set-up of masker and to-be-masked speech source	a masker's beneficial effect on objective performance was dependent on signal-to-noise ratio but also on the spatial set-up of masker and speech and the so-called better ear advantage; the maskers effects on subjective annoyance predominantly relied on signal-to-noise ratio.	a single, repeated taboo word produced no more disruption than a repeated neutral word; however, a sequence of different taboo words were more disruptive than a sequence of different neutral words; an unexpected taboo word inserted in a sequence of repeated taboo words, or inserted in a sequence of neutral words produced no more disruption than an unexpected neutral word in a sequence of repeated neutral words; further, differences in stable disposition for attentional control (Working Memory Capacity) did not modulate the unique disruption produced by taboo words, nor did it habituate following repetition
Sound quality	quiet vs. speech vs. 10 masking sound conditions in which pink noise was superimposed on the speech signal in two different signal-to-noise ratios; 5 different spatial set-ups of speech source and masker source position were used	quiet vs. dry recording of unmasked speech vs. open-plan office recording of unmasked speech vs. nine masked speech conditions	Taboo words or neutral words
Speech intelligibility			
Level	masking sounds: SPL = 45 dB(A); speech: SPL = 33 vs. 36 dB(A)	masking sounds: SPL = 45 dB(A); speech: SPL = 36 vs. 39 dB(A)	60 dB(A)
Office Type	open-plan office	open-plan office vs. "dry" recording of speech	
Performance	visual-verbal serial recall	visual-verbal serial recall	visual-verbal serial recall
Additional Information*	Annoyance: 5-point Likert scale and 11-point scale	Annoyance: 5-point Likert scale and 11-point scale	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[61] Röer et al. (2017b)**	**[62] Röer et al. (2018)**	**[63] Röer et al. (2019)**
Sample	university students; Exp. 1: n = 106 (72 females, between-participants; 18-48 years; mean age 23); Exp. 2: n = 74 (41 women; 18-39 years; mean age 23)	Exp. 1: 28 younger adults (university students; 21 women), 30 older adults (21 women), 28 fifth graders (14 girls), and 35 third graders (19 girls); Exp. 2: 38 younger adults (29 women) and 30 fourth graders (13 girls)	university students; Exp. 1: n = 60 (37 women); Exp. 2a: n = 70 (54 women); Exp. 2b: n = 47 (34 women); Exp. 3: n = 44 (38 women); Exp. 4: n = 89 (64 women)
Result	participants were given false information concerning whether task-irrelevant sound would be easy or hard to ignore; regardless of the presence of piano melody distracters participants who were informed the sound would be easy to ignore made more errors (Exp. 1); this effect was not observed for spoken text distracters (Exp. 2); subjective distraction was similar regardless of the information given; thus, expectations/metacognitive beliefs did not appear to modulate distraction	children (third, fourth and fifth graders) and younger and older adults were equally disrupted by auditory sequences of changing distracters and sequences comprising an unexpected auditory deviant, compared with a sequence in which the same distracter was presented.	semantic processing of task-irrelevant speech was demonstrated with a semantic mismatch effect; task-irrelevant sentences with unexpected endings produced more disruption than matched sentences with expected endings; this was observed when the sentence-final word was taken from a different proverb, or was a nonword phonologically similar to the expected word; however, a sentence final word that was both semantically and syntactically unexpected was not more disruptive compared with a sentence-final word that was only semantically but not syntactically unexpected
Sound quality	piano melodies, sentences	sequences comprising a repeated monosyllabic word, or different monosyllabic words	sentences with expected or unexpected endings
Speech intelligibility			
Level	65 dB(A)	64 dB(A)	56-60 dB(A)
Office Type			
Performance	visual-verbal serial recall	visual-verbal serial recall	visual-verbal serial recall
Additional Information*			

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[64] Röer et al. (2020)**	**[65] Schlittenlacher et al. (2019)**	**[66] Senan et al. (2018)**
Sample	university students; Exp. 1: *n* = 97 (67 females; mean age 24 years); Exp. 2: *n* = 90 (60 females; mean age 24 years)	mostly university students; Exp. 1: *n* = 55 (39 females; 18-51 years); Exp. 2: *n* = 40 (32 females; 19-46 years)	Exp. 1: 15 industry employees (8 females; 18-50 years); Exp. 2: 25 mostly university students (15 females; 18-50 years)
Result	task-irrelevant sentences conveying an unexpected ending produced more disruption than sentences containing an expected ending; this effect of semantic mismatch did not diminish (habituate) with repeated presentations of different sentences, or the same sentence, repeatedly presented throughout a block of trials comprising quiet and sentences with an without expected endings, presented in a random order	the disruption produced by task-irrelevant sound increased when both the spectral content (e.g., changes in relative loudness or intensity between frequency bands, over time) and the envelope (e.g., the total level of loudness over time) were changed but not when the envelope alone was changed; a constant loudness envelope produced the same level of disruption than when envelope changes were uncorrelated with spectral changes; spectral changes, therefore, appear to primarily drive disruption with envelope changes accentuating the disruption somewhat	performance decreased with the number of frequency bands up to the 6-bands condition, but there was no further influence of the number of bands on performance beyond six bands.
Sound quality	sentences with expected or unexpected endings	snippets of meaningful tests that were altered; noise-vocoded speech (independently manipulating loudness of 1, 2, 4, 8, or 24 channels [critical bands]); temporal segmentation of the speech signal holding constant the spectrum or level for durations ranging from 50ms to 14 s.	6-bands NVSS (noise-vocoded speech stimuli), 9-bands NVSS, 12-bands NVSS, 15-bands NVSS, 18-bands NVSS, silence (SLNC), and original speech (speech)
Speech intelligibility		dependent on resolution of noise-vocoded speech (number of channels)	
Level	60 dB(A)	60-65 dB(A)	average sound level of the stimuli was calibrated to 60 dB(A) L_{eq}
Office Type			
Performance	visual-verbal serial recall	visual-verbal serial recall	digit-recall task
Additional Information*		Moderator: concurrent changes in level appear to accentuate disruption produced by spectral qualities of task-irrelevant speech	Moderator: number of frequency bands.

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[67] Threadgold et al. (2019)**	**[68] Ueda et al. (2019)**	**[69] Vachon et al. (2017)**
Sample	university students; Exp. 1: *n* = 30 (15 females; 19-30 years; mean age 22); Exp. 2: *n* = 18 (12 females; 19-45 years; mean age 25); Exp. 3: *n* = 36 (23 females; 19-56 years; mean age 24)	81 mostly university students (47 females; 17-56 years) who were native German speakers and 83 university students (28 females; 18-37 years) who were native Japanese speakers	university students; Exp. 1A: *n* = 28 (16 females); Exp. 1B: *n* = 35 (19 females); Exp. 2A: *n* = 16 (7 females); Exp. 2B: *n* = 22 (14 females)
Result	background music impaired creative task performance, which was observed from instrumental music without vocals or music with vocals in a language not understood by participants; disruption occurred regardless of whether music induced a positive mood in the participants or whether they typically studied in the presence of background music; background library sounds had no effect on creative task performance; results at odds with the popular view that music enhances creativity	all forms of task-irrelevant speech were disruptive as compared with pink noise; when presented in a participant's own language (Japanese or German), task-irrelevant speech impairs performance more when presented as normal or as locally (short-segment) time-reversed (preserving speech intelligibility) as compared with long-segment time-reversed speech (low intelligibility); this differentiations were not observed for speech in a language not spoken by participants	evidence that an infrequent, deviant, sound impairs performance in a task-non-contingent fashion is reported; the impact of verbal deviants (a letter occurring amongst repeated presentations of the same letter) and spatial deviants (one sound occurring contra-laterally to the others) disrupted both verbal (visual-verbal recall) and spatial (visual-spatial recall) tasks
Sound quality	unfamiliar music with lyrics presented in a language foreign to participants; instrumental music (without lyrics); popular music; library sounds	pink noise; German and Japanese speech as mother tongue and foreign language speech - either untreated, locally time-reversed of different segment lengths, or globally time-reversed	spoken letters
Speech intelligibility		close to perfect at 20-ms segment duration, but almost none at 120 ms for locally time-reversed speech; no intelligibility for locally time-reversed speech played backwards regardless of duration of reversed segment	
Level	65-70 dB(A)	72 dB SPL pink noise; 74 dB SPL sentences	65 dB(A)
Office Type			
Performance	compound remote associates test; profile of mood states (PoMS)	visual-verbal serial recall	visual-verbal serial recall, visual-spatial serial recall, visual-verbal missing-item task, visual-spatial missing-item task
Additional Information*		Moderator: participant-spoken language: speech of greater intelligibility was more distracting only if presented in a language understood by the participant	

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[70] Vachon et al. (2019)**	**[72] Vasilev et al. (2019a)**
Sample	university students; Exp. 1A: *n* = 30 (12 females; mean age 24 years); Exp. 1B: *n* = 20 (14 females; mean age 30 years); Exp. 2A: *n* = 20 (11 females; mean age 22 years); Exp. 2B: *n* = 20 (14 females; mean age 24 years); Exp. 3A: *n* = 30 (17 females; mean age 23 years); Exp. 3B: *n* = 30 (20 females; mean age 24 years); Exp. 4: *n* = 29 (21 females; mean age 24 years); Exp. 5: *n* = 45 (34 females; mean age 26 years); Exp. 6: *n* = 24 (19 females; mean age 24 years); Exp. 7: *n* = 36 (31 females; mean age 25 years)	university students; Exp. 1: *n* = 40 (28 females; 18-40 years; mean age 22); Exp. 2: *n* = 48 (33 females; 18-27 years; mean age 20); Exp. 3: *n* = 48 (30 females, 18-32 years; mean age 21)
Result	evidence supporting automatic semantic processing of task-irrelevant sound was reported across 7 experiments; a categorical change in a sequence of task-irrelevant auditory stimuli (e.g., a digit among letters, or a “vegetable” among “animals”) disrupted performance on an unrelated visual focal task; disruption was independent of the personal significance of the task-irrelevant material, non-contingent on the task-set (it occurred with visual-spatial as well as visual-verbal tasks) and was not amenable to manipulations involving top-down cognitive control (e.g., task-difficulty, foreknowledge)	meaningful speech (English) as compared with quiet, speech-spectrum Gaussian noise and meaningless speech (Mandarin) had a limited effect on first-pass fixations of words and did not disrupt lexical access; however, meaningful speech as compared to the other conditions led to more regressions and rereading fixations; preventing participants from re-reading text disrupted its comprehension in the presence of meaningful speech but not the other sound conditions; the semantic, rather than phonological or acoustic properties of speech disrupt the reading process and do so after lexical access when words are to be integrated into a sentence context thereby permitting formation of a coherent discourse of the text
Sound quality	letters and digits, semantic category-exemplars	speech-spectrum noise, English speech and Taiwanese Mandarin speech
Speech intelligibility		
Level	65 dB(A)	59-61 dB(A)
Office Type		
Performance	visual-verbal serial recall; visual-spatial serial recall	reading comprehension; eye-tracking measures
Additional Information*	Task load: encoding load manipulated in Exp. 6	Moderator: Availability of text for regressions.

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[73] Vasilev et al. (2019b)**	**[74] Vasilev et al. (2021)**
Sample	48 university students (18-32 years; mean age 20)	64 university students (53 females; 18-31 years)
Result	fixations on target words were longer immediately after presentation of an unexpected deviant sound; no evidence that the deviant interfered with lexical processing since the word-frequency effect (longer fixations for long vs. short words) was not affected by the deviant against the standard	unexpected, deviant, sounds, as compared with standard repeating tones, presented during the second half of fixating a word (120 ms after onset) as compared with the first half of fixation (0 ms after onset) led to longer fixations; since saccadic planning occurs within the second half of fixation, the results suggest that deviant sounds disrupt the planning of saccades rather than their execution
Sound quality	standard sound was a 400-Hz sine wave; deviant sound was a burst of white noise	sinewave tone (400 Hz); 60 ‘novel’ sounds (drill, telephone ringing)
Speech intelligibility		
Level	binaurally at 65 dB(A)	65 dB(A) SPL
Office Type		
Performance	assessing performance in a complex sentence reading task by analyzing eye movements	eye-tracking measures
Additional Information*		Moderator: onset time of distracter in relation to fixation of visual word

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator

Author	**[75] Woestmann et al. (2020)**	**[77] Yan et al. (2017)**
Sample	university students; Exp. 1: *n* = 23 (12 females; mean age 25 years); Exp. 2: *n* = 6 (5 females; mean age 22 years)	42 university students (19-23 years)
Result	distracter onset time in approximately 2-4 cycles per second (Hz) modulated the magnitude of behavioural recall accuracy and distracter-evoked N1 component in ERP measure; an underlying rhythm of 2.5-Hz accounted for variation in behavioural and ERP measures; stronger phasic distracter encoding mediated lower phasic memory recall accuracy; suggests suppression of distracters fluctuates rhythmically and neural encoding of distracters is greater, resulting in enhanced memory disruption, when distracter onsets occur in periods of low distracter suppression	meaningful vs. meaningless background speech increased re-reading of Chinese; presence of meaningful and meaningless speech delayed the word frequency effect - the longer fixation times for low as compared with high frequency words; concluded that meaningful speech disrupts comprehension processes (as indexed by re-reading) and disrupted the early processing of words (as indexed by the delayed word-frequency effect in fixation times)
Sound quality	noise vocoded short German sentences	three conditions: meaningful irrelevant speech (Chinese), meaningless speech (scrambled Chinese), silence
Speech intelligibility	not measured but intelligibility of speech materials should be related to number of spectral bands used for vocoding (1, 4, and 32, in the study)	
Level	~65 dB(A)	58-66 dB(A)
Office Type		
Performance	auditory-verbal serial recall, memory maintenance of line-figures	examination of eye movements while reading Chinese sentences
Additional Information*	Moderator: rhythmicity of distracter encoding and memory recall	Moderator: presence of interpretable meaning from speech

*Task Load, Annoyance, Distraction, Perceived Disturbance, Mood, Health, Job Satisfaction, Environmental Satisfaction, Moderator