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Noise Effects on Human Performance: A Meta-Analytic Synthesis

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Noise is a pervasive and influential source of stress. Whether through the acute effects of impulse noise or the chronic influence of prolonged exposure, the challenge of noise confronts many who must accomplish vital performance duties in its presence. Although noise has diffuse effects, which are shared in common with many other chronic forms of stress, it also exerts its own specific influences on various forms of cognitive and motor response. We present a quantitative evaluation of these influences so that their harmful effects can be mitigated, their beneficial effects exploited, and any residual effects incorporated and synthesized into selection, training, and design strategies to facilitate human performance capacities. Predictions of single and joint moderator effects were made on the basis of major theories of noise and performance, specifically those explanations based on arousal, masking, or cognitive-resource mechanisms. These predictions were tested through moderator analyses of effects as a function of task type, performance measure, noise type and schedule, and the intensity and duration of exposure. Observed outcome effects (797 effect sizes derived from 242 studies) varied as a function of each of these moderators. Collective findings identified continuous versus intermittent noise, noise type, and type of task as the major distinguishing characteristics that moderated response. Mixed evidence was obtained for the traditional arousal and masking explanations for noise effects. The overall pattern of findings was most consistent with the maximal adaptability theory, a mental-resource-based explanation of stress and performance variation.

Keywords: noise, performance, meta-analysis

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Since the advent of the Industrial Revolution, noise has been a significant source of physical and psychological stress (Loeb, 1986). In modern times, noise exposures have increased in both duration and intensity as a result of the ubiquitous presence of handheld devices that provide auditory stimulation in the form of speech and music. Noise has broad effects, ranging from interference with cognitive processing (Smith, 1983) to detrimental effects on mental and physical health (Clark, 1984). Understanding the factors that moderate the relationship between noise and human response is therefore crucial to areas of concern that range from general theories of stress to the pragmatic design of occupational noise mitigation strategies. As a consequence of these manifest and diverse concerns, the primary goal for the current meta-analytic review is to quantify the influence of variations in the characteristics of noise in conjunction with those of the task to be performed to elucidate the complex relationship between this form of stress and response efficiency (see also Hancock & Desmond, 2001). We adopt, as a fundamental foundation, the maximal adaptability theory of stress (Hancock & Warm, 1989), which views the task to be performed as the proximal source of performer stress. It is thus the combination of task demands and environmental stimulation (e.g., noise) that subsequently determines the degree to which an individual adapts to and copes with the task demands in context.

Noise as a Physical Stimulus

Noise is one primary example of an environmental stressor. There are a variety of others, which include vibration, thermal variation, atmospheric gas content, and so forth. These sources have been the topic of prior detailed meta-analytic and synthetic evaluations (see Broadbent, 1971; Conway, Szalma, & Hancock, 2007; Hancock, Ross, & Szalma, 2007; McEwen, 2002; Poulton, 1970). Sound, and its appraised correlate noise, is the result of vibration within any physical medium. Exclusively in the present review, this medium is air. Oscillations of the particles in the

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medium cause a change in the pressure of that transmitting medium that constitutes the ambient sound waves. Like other forms of energy, these vary in amplitude and frequency (Jones, 1983). Sound waves can also vary in terms of their duration and precise waveform. In terms of waveform, the temporal characteristics of the wave itself may be intermittent (aperiodic) or continuous (periodic). Continuous noise is constant, with no breaks or changes in intensity. A form of continuous noise often utilized in laboratory-based empirical investigations is white noise, which consists of equal pressure levels in every frequency band across the whole frequency range (Speaks, 1999). Intermittent noise changes in intensity over a given period of time, having gaps of relatively quiet intervals between repeated louder phases of the signal. In addition to these forms of noise (e.g., white noise, machinery-generated noise, etc.), a major type of practical distractive noise is speech. Speech is a distracter to which humans are especially attuned. Even manifestly irrelevant speech is monitored to some degree, as evidenced in the famous cocktail party name recognition effect (see Cherry, 1953; Pashler, 1998).

The most common measurement method for assessing the magnitude of sound is the decibel (dB) scale. Decibels represent a logarithmic scale based on the intensity of the stimulus (using sound pressure measurements). An increase of 3 dB approximates a doubling of the sound pressure level. Because the human ear does not have equal sensitivity to stimuli over the entire frequency and sound pressure ranges (Fletcher & Munson, 1933), the dB scale does not entirely equate to what an observer perceives. The apparent subjective loudness of a stimulus is therefore a function not just of the intensity but also of the duration, variation of intensity, and frequency of the sound waves (Engel, Augustynska, Koton, & Kacmarska, 2006). Modern measurement devices incorporate this complexity by weighting the assessment to the ranges of the two factors to which the human ear is sensitive. The weighted scale for the human ear produces measurements termed *A-weighted decibel* levels, denoted dB(A). Much of the reported noise stress in the present review uses this expression of the physical stimulus.

Noise and Performance: Noise Effects on Information Processing

A vast amount of effort has been devoted to the investigation of the effects of noise on nonauditory aspects of performance, such as information processing, attention, and memory. However, the mechanism by which information processing is affected has been the source of much debate. The majority of extant research has examined only intensity (magnitude) effects on performance, although results from these investigations have been largely equivocal. Such early findings prompted Broadbent (1958) to suggest that only specifically sensitive tasks should be used in the investigation of stress effects—that is, tasks of long duration and either very high or very low information presentation rates (and also see Poulton, 1970).

Hockey and his colleagues (Hockey & Hamilton, 1983; Hockey, 1984) reviewed a large body of literature on the effects of different types of stressors on several components of cognitive performance. Although commonalities exist across stressors (e.g., alcohol, depressant drugs, and fatigue all cause a reduction in general alertness and activation), each stressor was considered to have a unique signature pattern when all performance indicators were considered. Hockey (1997) also distinguished between the structural and the strategic effects of stress. Structural changes are those that occur in basic processing components (e.g., attentional narrowing), and strategic effects manifest as compensatory response (e.g., increased effort, speed–accuracy trade-offs). Hence, noise may affect performance by impairing information processing or, alternatively, by inducing shifts in strategic response. There is evidence of both forms of stress effect. Specifically, noise increases levels of general alertness/activation and attentional selectivity. It does not influence performance speed, but it reduces performance accuracy and short-term/working memory performance. However, the current state of the empirical literature on noise effects does not address these parameters to an extent necessary for meta-analytic evaluation.

Another mechanism that possibly underpins noise effects on performance is the degradation of working memory (Hockey, 1986). Jones (1993), for example, argued that it is in the context of working memory tasks that the strongest noise effects are likely to occur. One reason may be the distraction of attention away from the task at hand or a particular component of it (in this case, the rehearsal of the information held in the working memory) and toward the task-irrelevant noise stimuli. Thus, the material held in the working memory at that point in time becomes degraded (see Brown, 1958; Peterson & Peterson, 1959). This effect, which is not specific to noise alone, is thought to be closely linked to the observed effects of stress on situation awareness (Orasanu, 1997). A noise-specific mechanism of working memory decrement is that of the disruption to material held in the articulatory loop component. As this short-term storage mechanism (see Baddeley & Hitch, 1974) rehearses the information in an auditory format (often labeled *inner speech*), the potential for auditory noise to disturb this process is intuitively appealing.

An alternative explanation underlying noise effects is based on the fact that noise has been found to increase the mental workload imposed by a given task environment, thereby reducing the cognitive resources available for allocation to task performance (A. B. Becker, Warm, Dember, & Hancock, 1995). This effect seems intuitive, given that (a) noise causes annoyance (De Coensel et al., 2009; Smith, 2003) and (b) stressors have been shown to distract attention to task-irrelevant thoughts (Sarason, Sarason, & Pierce, 1990). One type of task-irrelevant thought that may be found in these situations is worry. Matthews (2001) described how subjective appraisals of threat to current goals cause worry if performers deem that the level of demand (of the task and the environment combined) exceeds their coping potential (see also Matthews et al., 2002). Hence, individuals have to invest more effort into task performance in the presence of noise, as has been found through self-report measures and endocrine markers of effort (e.g., Lundberg & Frankenhaeuser, 1978).

Noise and Performance: Differential Effects of Noise Characteristics

Although the intensity and duration of exposure have been the primary foci of concern in research on noise effects (as well as other sources of stress; see Conway et al., 2007; Hancock et al., 2007), there are other noise characteristics that have been identified as potential performance moderators. Two of those considered in the present meta-analysis are the schedule and type of noise exposure.

Noise Schedule

One of the most disturbing forms of noise, at least intuitively, is that of intermittent noise. The source of performance perturbation in such situations is posited to be the distraction of attention away from the task and to the source of the noise. When the intermittent noise occurs at high intensities, the performer briefly diverts his or her attention to the noise in the form of an orienting response. Such startle responses are maximized under so-called *impact noise*, that is, relatively infrequent and short duration bursts of noise (Casali & Robinson, 1999). Loeb (1986) argued that intermittent noise is more disruptive than continuous noise but that it is the change in intensity rather than the intermittency per se that is responsible for performance effects. Noise schedule was included in the present meta-analysis to formally test the generally held expectation that intermittent noise should be more disruptive than noise presented on a continuous schedule.

Noise Type

The disruptive potency of irrelevant speech was demonstrated by Salamé and Baddeley (1982), who observed negative effects of irrelevant speech but not of broadband noise on serial recall performance. However, Jones (1993) argued that the observed performance decrements are not a direct function of the noise intensity per se or of the informational content of the speech (see also Jones & Morris, 1992). Jones proposed the object-oriented episodic record model of the effects of noise on performance, specifically on serial recall tasks. Jones argued that auditory stimuli are represented in memory as *objects* that are formed by segmentation, which results from correlated changes in the physical attributes of the sound, such as frequency and intensity. Objects are linked to one another to form *streams,* and it is the strength of the linkages in streams that is time limited and, therefore, a determining factor of serial recall performance. Thus, from the perspective of Jones's model, the information to be recalled is considered relatively stable; it is the links between pieces of information that limit response capacity. The streams are navigated in memory by means of *threads,* which are paths among objects in a stream that are traversed when serial recall is required. The interference by auditory stimulation results from competing threads (i.e., for processing of noise and of task-related information). Because the process of object and stream formation depends on a process of segmentation based on the physical characteristics of the sound, the semantic content of the noise is irrelevant.

More recently, Macken, Phelps, and Jones (2009) proposed that the disruption of working memory performance results from interference due to competition of task-relevant and task-irrelevant sequences of information. That is, the serial recall of a sequence of items is disrupted by the sequence of segments of irrelevant sound. Macken et al. argued that their model accounts for the finding that irrelevant sound disrupts memory for item sequence but does not interfere with memory for the items themselves. However, this model is a fine-grained theoretical account of the irrelevant speech effect, and as such, it does not necessarily generalize to all effects of noise on performance. Indeed, the consideration of noise as a competing source of information leads to predictions similar to those of the maximal adaptability model. The latter theory also conceptualizes noise as a form of (irrelevant) information, but from this perspective, noise is considered one source in an environment consisting of multiple information inputs. Hence, in the present work, we evaluate the effects of noise on performance from the more general theoretical account proposed by Hancock and Warm (1989) and contrast this position with two traditional arousal-based models (Broadbent, 1971; Poulton, 1979).

Explaining Overall Noise Effects: Three Theoretical Perspectives

The Broadbent–Poulton Debate

Over 30 years ago, Donald Broadbent (1976, 1977, 1978) and Christopher Poulton (1977, 1978, 1979) engaged in a now classic and polemical theoretical debate regarding the mechanism responsible for noise effects on performance, elements of which were published in *Psychological Bulletin*. This was followed soon after by an equally interesting exchange between Hartley (1981a, 1981b) and Poulton (1981a, 1981b) on the same fundamental issue.

Arousal and attention. Broadbent (1978) invoked an arousal induced attentional narrowing mechanism to explain noise effects (see Figure 1). From this perspective, noise (as well as other sources of stress) increases arousal which decreases the breadth of attention (Easterbrook, 1959; Hebb, 1955). At relatively lower levels of arousal, the attentional narrowing facilitates performance because it causes the individual to exclude irrelevant cues. Beyond an optimal level, however, increases in arousal cause increased narrowing so that task-relevant cues are also excluded, and performance is thus impaired.

Arousal and masking. Poulton (1979) argued for a composite model of noise effects involving arousal and masking of inner speech (see Figure 2). From this perspective, the gains in performance in continuous noise early in the task occur because the increase in arousal compensates for the deleterious effects of masking. However, with time on task, arousal decreases, and masking effects subsequently dominate. Note that both Broadbent and Poulton included arousal as a component of their explanations

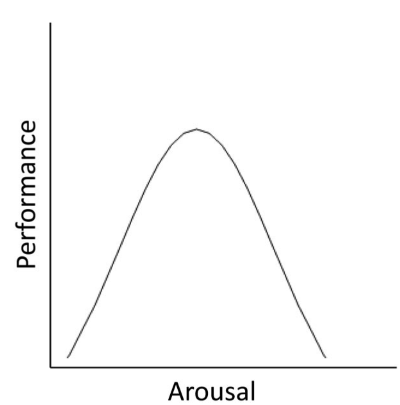

Figure 1. Arousal theory of stress and performance.

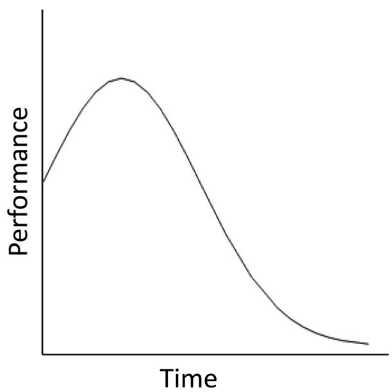

Figure 2. Poulton's composite model of continuous noise stress and performance. Adapted from "Composite Model for Human Performance in Continuous Noise," by E. C. Poulton, 1979, *Psychological Review, 86,* p. 362. Copyright 1979 by the American Psychological Association.

of noise effects; however, they differed in the mechanism by which arousal affected performance.

Maximal Adaptability Theory

The maximal adaptability model of Hancock and Warm (1989) proposed that stress can be represented in three loci (see Figure 3). *Input* consists of all objective environmental and task factors that affect performance (e.g., noise, task-related memory demand, etc.). The *adaptive processes* represent the capacity of the performer to cope with demands intrinsic to an environment (e.g., physiological coping responses, psychological adjustment and appraisal; see also Lazarus & Folkman, 1984). Finally, the *output* refers to the subsequent pattern of behavioral response in relation to the task environment (typically, the efficiency of task performance most often reflected as response speed and response accuracy). The output is heavily dependent on the characteristics of individual performers themselves. It is therefore the locus of stress at which the greatest variability in stress response is observed across individuals. The direct effects of noise on performance manifest themselves in changing output. In terms of adaptation, noise can impair capacity through the masking or distortion of task-relevant auditory information; it can also disturb or mask an individual's vocal response in the same manner.

According to the maximal adaptability theory, individuals are able to adapt to a fairly broad range of stress magnitudes (see Figure 4). However, at the extremes of overload and underload, there is a threshold of dynamic instability in which adaptation fails, and precipitous performance decrements become evident. In their original description of the theory, Hancock and Warm (1989) noted that not all sources of stress would be symmetrical in terms of overload and underload. Noise was typically cited as an example in which the input would be biased toward the overload side of the model, although conditions close to absolute zero dB(A), which can be achieved in specialized anechoic chambers, can themselves prove very disruptive. Hancock and Warm further asserted that stressors could be delineated into two dimensions: information structure and information rate (see Figure 5). Information structure refers to the spatial organization of the input stressor or task, and information rate reflects the temporal properties of that input. As can be seen in Figure 5, these dimensions together determine the level of adaptive function of an individual performing under stress. In our previous meta-analytic reviews (Conway et al., 2007; Hancock et al., 2007), we observed that the task dimensions of information rate and structure were primarily reflected in the effects of duration of exposure and intensity of the stressor, respectively.

Purpose of the Current Work

As is evident from the foregoing, the diverse ways in which noise influences performance response are still uncertain. Thus, improvement in the theoretical and empirical understanding of noise stress can be facilitated by substantive and reliable quantitative information as to how noise effects vary as a function of the characteristics of the noise itself and of the task to be performed. Therefore, the primary goal for the current work is to provide such information by means of a meta-analytic review concerning the influence of noise on human perceptual, cognitive, and psychomotor response capacities, as well as tasks requiring communication of information (we selected broad task categories to ensure a sufficient number of effect sizes for stable estimates of parameters in the moderator analyses). The advantages in conducting a meta-analysis are that it provides a quantitative synthesis of the literature, controlling for sampling error and the low power of individual studies while permitting an examination of potential moderating variables (see Cooper & Hedges, 1994; Hunter & Schmidt, 2004; Lipsey & Wilson, 2001).

On the basis of the theoretical explanations for noise effects as well as previous synthetic efforts (e.g., Loeb, 1986), the noise characteristics examined in the present study were schedule, type,

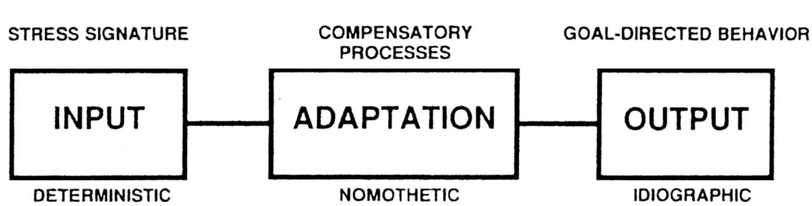

Figure 3. The *trinity of stress*. A tripartite descriptive framework for describing the environmental origin of stress (input), its representation as a direct pattern of adaptive, regulatory responses (adaptation), and its manifestation in disturbance to ongoing performance capacity (output). From "A Dynamic Model of Stress and Sustained Attention," by P. A. Hancock & J. S. Warm, 1989, *Human Factors, 31,* p. 520. Copyright 1989 by the Human Factors and Ergonomics Society.

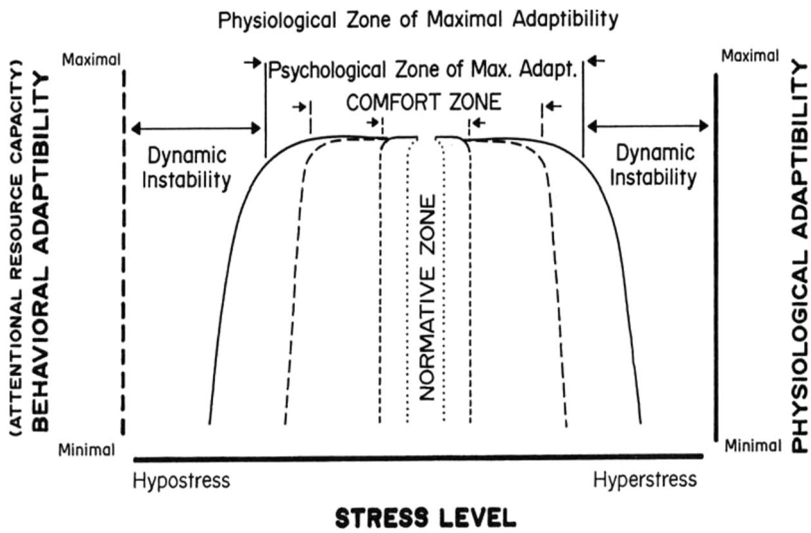

Figure 4. The maximal adaptability model of stress and performance. From "A Dynamic Model of Stress and Sustained Attention," by P. A. Hancock & J. S. Warm, 1989, *Human Factors, 31,* p. 528. Copyright 1989 by the Human Factors and Ergonomics Society.

intensity, and duration of exposure. In addition to these, the moderating effects of type of task and dependent measure were evaluated. Furthermore, specific interactions among the moderator variables were examined by means of hierarchical moderator analysis to test the facets of the three primary theoretical perspectives we considered. Note that for exploratory purposes, other interactive effects were evaluated, but these effects are summarized in the supplemental materials.

Predictions of the Three Theories

With respect to the variables analyzed here, the three theories noted earlier lead to similar predictions of noise effects for certain conditions (e.g., noise schedule, intensity, and duration) but different predictions for other categories (e.g., speech vs. nonspeech and interactions of moderator variables with intensity and duration). In the case of noise schedule, the three theories make a common prediction that intermittent noise should induce greater performance impairment than continuous noise. However, the three theories differ in how schedule interacts with other moderating variables. Next, we derive predictions from the three theories and then specify the hypotheses to be tested through moderator analyses.

Arousal Theory

On the basis of the arousal conception (e.g., Hebb, 1955), theorists such as Broadbent (1971, 1978) would predict that the more demanding tasks should have lower levels of optimum arousal and, therefore, should yield the greatest performance decrements in the presence of noise. Hence, cognitive and communication tasks should suffer greater magnitudes of performance impairment compared with perceptual and psychomotor tasks. Also, because arousal is influenced by the intensity of the noise and time on task (Broadbent, 1971), one would expect that higher intensities and longer durations should have greater negative effects. Because the effect of noise is one of overarousal and attentional filtering, one would not expect differences as a function of noise type (i.e., speech vs. nonspeech). Instead, the intensity and duration of exposure should be the most influential moderators. Given the high level of arousal in the presence of noise, one would predict greater impairment of accuracy than of speed (speed may even be facilitated by the presence of noise). The effects on accuracy should be stronger for the cognitive and communication task categories relative to perceptual or psychomotor tasks. With respect to schedule, intermittent noise should impair performance more than continuous noise across levels of the other moderating variables. In summary, on the basis of arousal theory, it was predicted that noise effects should be moderated by task type, dependent measure, intensity, duration, and noise schedule. The theory also led to the prediction of hierarchical or interactive moderating effects, specifically for Task × Dependent Measure and for Intensity × Duration. This specific pattern of outcome prediction is subsequently compared with the results of the present meta-analysis.

Composite Theory

Poulton's (1979) composite theory predicts that noise effects should not vary substantially as a function of the task, noise type, or intensity per se but should degrade performance only for those conditions in which inner speech is masked. To the extent that inner speech is a component of all tasks, as Poulton (1979) seemed to imply, masking should not vary as a function of task or noise type. However, Poulton (1981a) argued that accuracy should be more impaired than speed. Noise intensity should moderate noise effects, but given that even relatively low intensities can mask inner speech, the moderating effect should be restricted to those studies in which the noise condition was compared with a quiet control condition that did not receive noise exposure and may be attenuated in those studies in which the noise exposure occurred in both control and experimental conditions. According to the com-

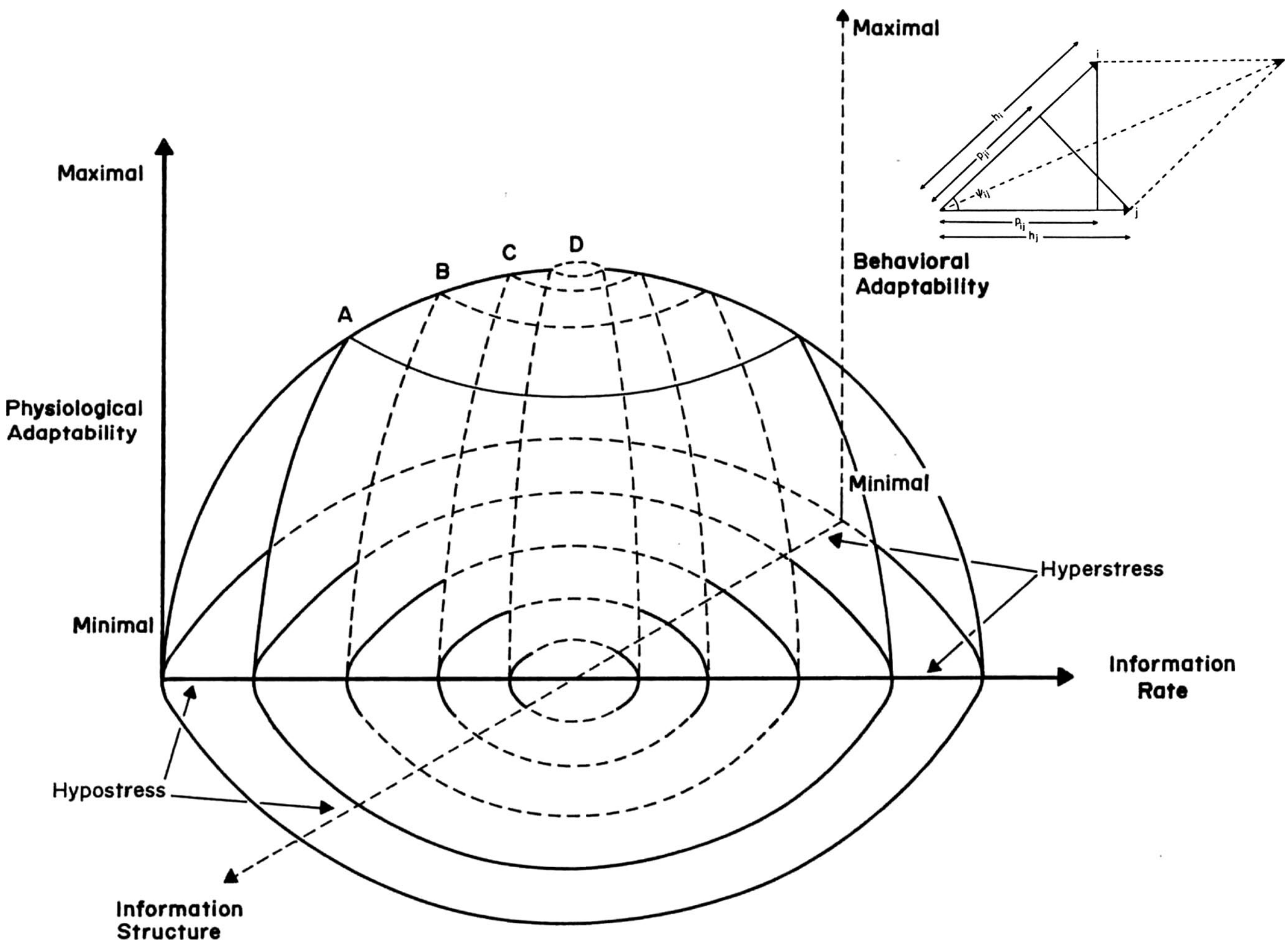

Figure 5. Extension of the maximal adaptability model with the stress dimension differentiated into two dimensions of task characteristics. From "A Dynamic Model of Stress and Sustained Attention," by P. A. Hancock & J. S. Warm, 1989, *Human Factors, 31,* p. 529. Copyright 1989 by the Human Factors and Ergonomics Society.

posite theory, duration of exposure should be a particularly important moderating variable; noise should facilitate performance at shorter durations because of arousal but should impair performance at longer durations as a result of declining arousal accompanied by masking. Further, this effect should be stronger for continuous as compared with intermittent noise, as the composite model was designed to be applied to the former schedule. Poulton (1979) argued that intermittent noise exerted its effects because of its disruptive characteristics rather than a combined arousal/masking mechanism. However, intermittent noise would be expected to have a stronger negative effect than continuous noise as a result of such disruption, but this effect would not be expected to vary as a function of duration. In summary, on the basis of the composite theory, noise effects should be similar across task and noise type, but moderating effects are expected for intensity, duration, schedule, and dependent measure. An interactive effect is expected for Duration × Schedule. Again, this pattern of predicted responses was compared with the actual outcome.

Maximal Adaptability Theory

From an attentional-resource-based perspective, which is subsumed under the maximal adaptability theory, performance impairment should occur to the extent that noise consumes information-processing capacity by devoting it to compensatory effort. On the basis of the maximal adaptability theory, the combination of factors that poses the greatest demand on a person's resources and limits the efficacy of compensatory effort should be the most debilitating. Hence, performance on more resource-demanding cognitive or communications tasks should be more impaired than performance on perceptual or motor tasks, and these differences should manifest more strongly for accuracy compared with speed. Furthermore, an Intensity × Duration interaction would be expected, as both of these characteristics can, separately and together, divert resources away from task performance to compensatory efforts (Hancock & Szalma, 2008; Hockey, 1997). Greater impairment should therefore occur for higher intensities and longer durations. In addition, the differences in impairment as a function of task category should also depend on type of noise (speech noise should be more disruptive than nonspeech because of the greater competition for resources, particularly for cognitive tasks; Wickens, 2002). For dependent measures, the resource-based view would predict that the pattern of effects should depend on the strategy adopted by the individual (i.e., whether the person exhibits a speed–accuracy trade-off), although as noted earlier, dependent measures may exhibit different patterns as a function of task type. Note, however, that the aforementioned distinction between structural and strategic effects (Hockey, 1997) is not explicitly differentiated in the maximal adaptability model, and this distinction was thus not considered explicitly here. In summary, the maximal adaptability theory leads to the prediction that noise effects should vary as a function of the type of task, noise, and schedule, as well as the duration and intensity of exposure. Also, on the basis of this perspective interactions are expected for Intensity × Duration, Noise Schedule × Type, Task × Dependent Measure, and Task × Noise Type. Again, this pattern was compared with the meta-analytic outcome.

Analytic Methodology

Literature Accumulation

The literature search was performed with the PsycINFO, MEDLINE, and Dissertation Abstracts International databases. To maximize the potential for the searches to find suitable sources, the primary search terms *noise* and *speech* were combined with the secondary terms of *memory, decision-making, problem-solving, attention, vigilance, tracking, marksmanship, shooting, fine motor,* and *gross motor*. In addition, we used several Web-based search engines, for example, Google, and their specialized derivates, such as Google Scholar, to seek further references not discovered in the initial formal scan. After a preliminary listing of articles was derived, additional articles were collected by surveying the reference lists from the already available articles and by retrospectively examining article citations through Science Citation Index. Examination of these data as source citation neared completion indicated that the means and variances did not change substantially with the addition of new studies. Furthermore, no other publications were identified that included study characteristics in relatively unpopulated categories (e.g., communication, psychomotor tasks). Thus, we considered the publications we collected to be representative of the literature on the effects of noise on human performance. Our cutoff date for the present information was February 5th, 2011. The overall process resulted in the identification of 483 articles, reports, dissertations, and theses.

Identified Criteria for Study Inclusion

All studies were inspected to ensure that they fulfilled the following six criteria for inclusion in the meta-analysis:

1. Each study had to report an empirical examination of noise stress in which the experimental manipulation used an application of noise exposure. We did not include studies in which the participants themselves generated noise. Thus, for instance, studies on cell phone use while driving were excluded, because the emphasis of such research is on distracted driving, the noise is partially generated by the drivers themselves, and noise is not the only source of distraction in these circumstances.

2. Each report was required to include a control group that experienced a baseline quiet condition or received lower intensities of the noise stress. There might be two separate groups (between-groups design) or one group taking part in each separate session—a control session and an experimental session. In all cases, the experimental condition featured a noise exposure that was compared with either a lack of input noise stress or a control group in which the input noise was of lower intensity. If the control condition also featured noise exposure, then the experimental condition consisted of a higher level of noise stress input.

3. The study had to address the issue of direct noise effects on performance. Hence, studies that sought to disturb sleep through the application of a noise and then assess the effect of sleep loss on performance were not included in this analysis. Multistress studies were not excluded, but only the noise effects were considered in such cases.

4. Each study had to report at least one measure of performance (e.g., proportion correct, speed of response, tracking error, etc.). Studies using physiological or subjective response alone were thus excluded.

5. Each study had to include sufficient information regarding performance results to determine effect size estimates.

6. The study had to use a sample of healthy adults. That is, the study was rejected if it used children as participants or if the sample consisted of individuals with hearing impairment or any mental or physical illness. The majority of studies either included both men and women or did not provide information regarding gender. Similarly, the majority of studies did not report mean age, although among those that did report this information, the ages ranged from 18 to 57 across studies.

As a result of this screening process, a total of 483 studies were evaluated. Of these, 242 primary studies were accepted for use in the meta-analysis. The included studies provided a total of 797 effect sizes. The rejection of numerous primary studies in a meta-analysis is common and necessary to ensure meaningful data when combining effect size estimates across studies.

Meta-Analytic Results

Calculation of Effect Size

Effect sizes were formally determined through the mathematical examination of the standardized mean difference between the cited experimental and the control conditions. The effect sizes used in this meta-analysis were standardized difference scores (Hedges's *g*; Hedges & Olkin, 1985; Hedges, Shymansky, & Woodworth, 1989). In cases where means or standard deviations were not available for direct computation of *g* but other data were available to compute an effect size (e.g., sum of squares, *t* tests, 1-*df F* tests), effect sizes were computed with formulas provided by Lipsey and Wilson (2001). In calculating the effect size, its directional sign was specified to ensure that positive scores represented superior performance in the experimental group relative to the control group, whereas negative *g* scores indicated worse performance in the experimental condition. We adjusted the obtained *g* scores for statistical bias, using the procedure described in Hedges and Olkin, (1985, pp. 78–81). Following our previous procedures (Conway et al., 2007; Hancock et al., 2007), our general approach followed that of Hunter and Schmidt (2004) except that each effect size was weighted by the reciprocal of the sampling variance rather than sample size. Although the latter is a more pragmatic measure, the former yields more precision (cf. Hedges & Olkin, 1985; Lipsey & Wilson, 2001; Morris & DeShon, 2002).

Combining Effect Sizes Within Studies

Most of the 242 studies reported here provided data for computing multiple effect sizes (again, there were 797 effect sizes across the 242 studies). Multiple effect sizes within a given study were therefore based on the same sample of participants. As in most other areas of statistical assessment, the procedures for meta-analysis assume that the observations (i.e., individual effect sizes) are independent of one another. Violations of this assumption lead to underestimation of variances (Hunter & Schmidt, 2004; Martinussen & Bjornstad, 1999). Currently, there are no techniques for estimating the degree of statistical dependence among *g*s (although such procedures have been developed for correlational effect sizes; see Cheung & Chan, 2004). Problems associated with the independence assumption are generally intrinsic to meta-analysis and are not solely a characteristic of the current work. To avoid violations of independence, we therefore used the same approach adopted in our previous meta-analytic work (Conway et al., 2007; Hancock et al., 2007). In this approach, the effect sizes within studies are averaged (after the adjustments for statistical bias described earlier) prior to estimating means and variances (see Lipsey & Wilson, 2001). In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable. For instance, if a particular study contributed an effect size for each performance measure (accuracy and speed), these effect sizes were not averaged for that moderator analysis but were included in their respective groups. Because the levels of the moderator variables were never formally compared (i.e., through statistical significance testing), this does not represent a violation of the independence assumption. However, for the global analysis and other moderator analyses not including performance measures, these effect sizes were averaged. The number of studies within each level of a moderator variable therefore does not necessarily sum to the total number of studies included in the global analysis.

Adjustment for Experimental Design

Effect size estimates based on standard deviation metrics, such as *g,* are not necessarily equivalent across experimental designs because the standard deviation units vary depending on the design used (e.g., standard deviation of raw scores vs. the standard deviation of difference scores used in a paired-samples *t* test; see Hunter & Schmidt, 2004; Morris & DeShon, 2002). To combine results from both within- and between-participant designs, the effect size estimates must therefore be converted to a common metric. We accomplished this by converting repeated measures *g* scores to the *raw score metric,* using techniques described by Morris and DeShon (2002; see also B. J. Becker, 1988).

Estimation of Variances

For computation of variance estimates, we used procedures for the random effects model described by Hunter and Schmidt (2004). In this approach, two sources of variance are identified: variability due to sampling error (σ_e^2) and variability due to differences in the population effect sizes (σ_δ^2). The latter variance estimate is obtained by estimating σ_e^2 and the observed variability among the effect sizes (σ_g^2), and then subtracting σ_e^2 from σ_g^2. The difference between the total variance and the sampling error variance is residual variability σ_δ^2 that arises from *random effects* (Hunter & Schmidt, 2004; but see also Hedges & Vevea, 1998), the effect of moderator variables, and uncorrected sources of statistical bias (e.g., measurement error). To interpret the relative magnitudes of the variances, Hunter and Schmidt recommended the *75% rule*. According to this guideline, if 75% of the observed variance is due to sampling error, it is likely that most of the other 25% of the variance is also artifactual in nature. Cases in which this condition is not met can be interpreted as instances in which the residual variance likely includes real variance due to random effects and/or the presence of moderator variable effects. Hunter and Schmidt argued that the 75% rule is at least as powerful as significance tests for homogeneity among effect sizes. In cases with small numbers of studies, as occurred in the hierarchical moderator analyses in the present study, this rule is actually more powerful. A large σ_δ^2 indicates that there is variability among the observed effect sizes that cannot be accounted for by sampling error and that there are likely to be one or more variables moderating the magnitude of the effect in question (see Hunter & Schmidt, 2004, p. 288). Note that if all of the observed variance in the effect sizes were accounted for by sampling error, then $\sigma_\delta^2 = 0$, which is the assumption of fixed effects models (see Hedges & Olkin, 1985).

Estimation of ρ

Many studies identified in the present meta-analysis used within-participant designs. Calculation of the variance associated with each effect size in such designs requires an estimate of the population correlation coefficient (ρ) between the experimental and control conditions (sometimes referred to as the pretest–posttest correlation; see Morris & DeShon, 2002). In addition, adjusting effect sizes to a common standard deviation metric also requires an estimate of ρ. Using the formulas presented by Morris and DeShon (2002), ρ estimates were computed for studies providing the necessary information (means, standard deviations, and a *t* or 1 *df F* test). In total, five ρ estimates from five studies were obtained. These correlations were combined meta-analytically to yield a weighted average ρ value, $\rho = .46$. This value was then used to compute the variances according to procedures in Morris and DeShon (p. 117).

Moderator Analyses

A limitation of hierarchical moderator analyses is that division of effect sizes into separate categories necessarily reduces the number of effect sizes on which means and variances are estimated. Indeed, we limited the number of levels within each moderator variable to minimize this problem to the extent possible. Thus, there are cases in which some levels of a moderator variable contain only a small number of studies (and, of course, sometimes only one or even no studies). Estimates from such limited information should thus be interpreted with the appropriate caution as we indicate at each appropriate juncture. Such situations, however, serve to reveal the paucity of studies examining particular combinations of relevant variables. Therefore, they point toward the need for further experimentation to reliably identify these effects.

Outlier Analyses

In some cases, large variance estimates were obtained, which can result from the presence of outliers in the sample (Hunter & Schmidt, 2004). Thus, in cases in which the observed or sampling error variance was substantially larger than other variance estimates in the analysis ($s_\delta^2 < 1$), outlier analyses were performed with procedures described by Huffcutt and Arthur (1995). The analysis parameters were then recomputed with the outliers removed to assess whether and how the outliers influenced the results. These reanalyses are, for completeness, included in the tables containing the analyses with the full sample.

Meta-Analytic Results

We obtained 242 useable studies from a collective survey of 483 publications. This represents an acceptance rate of 50.1%, which is quite high given the imposition of our stated criteria. A total of 797 effect sizes were derived from the 242 studies. The results of the meta-analysis are presented in Tables 1 through 8. The first result for the global analysis, drawn from the 242 total studies, shows a small-to-medium effect ($g = -0.31$; see Table 1), indicating that performance is generally degraded by noise. However, inspection of the variances indicates heterogeneity of effect sizes, confirming the need for moderator analyses.

Single Moderator Effects

Task type. In the category of visual perception, 40 studies qualified, which yielded an average effect size of $g = -0.06$, and the 95% confidence interval (CI) for this effect contained zero (i.e., no effect). Such an outcome suggests that the effect of noise on the visual aspects of perception is rather negligible. However, the total variance was substantial relative to error variance, indicating that there are other variables that moderate the effect of noise on performance of perceptual tasks (see Table 1).

With respect to cognitive tasks, 191 qualifying studies were identified, with an average effect size of $g = -0.34$ and a 95% CI that did not contain zero. However, eight outliers were identified: Banbury and Berry (1998, Experiment 2); Barker and Cooke (2007); Enmarker, Boman, and Hygge (2006); Marsh, Hughes, and Jones (2008, 2009); Skowronski and Harris (2006); Weisz and Schlittmeier (2006); and Wong et al. (2009). Removal of these outliers resulted in a somewhat larger effect ($g = -.43$) and smaller observed variance. Thus, there is a small-to-medium deleterious effect of noise on performance of cognitive tasks. It is also interesting to note that this level of degradation closely replicated the overall general effect.

Relatively few studies were found that examined the effect of noise on psychomotor performance. Eleven studies were identified that examined motor processes under noise, yielding an average effect of $g = -0.47$, with an estimate of sampling error variance larger than the observed variance of the effect sizes. This almost medium-sized negative effect of noise may therefore be considered homogeneous. A surprising finding was the relatively low number of studies (17) that examined the extent to which noise affects tasks requiring oral or written communication. Aggregation of these studies yielded a medium effect size ($g = -0.53$) reflecting degraded performance under noise. Further, this effect is consistent across the 17 studies (i.e., the effects are homogeneous), as the sampling error accounts for all the variance in effect sizes (see Hunter & Schmidt, 2004).

Table 1
Noise Meta-Analysis Results: Global, Task Category, and Dependent Measure Analyses

Category	k[b]	$\bar{g}$	s_g^2	s_e^2	s_δ^2	s_e^2/s_g^2	95% CI	N
Global	242	−0.31	1.13	0.31	0.82	0.28	[−0.44 < δ < −0.17]	13,887
Task category								
Perceptual	40	−0.06	0.29	0.14	0.15	0.50	[−0.17 < δ < 0.06]	4,165
Cognitive	191	−0.34	1.55	0.35	1.19	0.23	[−0.42 < δ < −0.25]	9,474
Cognitive[a]	183	−0.43	0.61	0.33	0.28	0.54	[−0.51 < δ < −0.34]	8,994
Motor	11	−0.47	0.14	0.20	—	—	[−0.74 < δ < −0.21]	345
Communication	17	−0.53	0.14	0.4	—	—	[−0.83 < δ < −0.23]	573
Dependent measure								
Accuracy	218	−0.43	1.28	0.34	0.94	0.26	[−0.51 < δ < −0.36]	10,566
Accuracy[a]	211	−0.48	0.67	0.32	0.35	0.47	[−0.56 < δ < −0.41]	10,110
Speed	48	−0.14	1.24	0.05	1.19	0.04	[−0.21 < δ < −0.08]	4,355
Speed[a]	45	−0.14	0.34	0.06	0.28	0.19	[−0.21 < δ < −0.07]	4,306

Note. k = number of studies included in the analysis; $\bar{g}$ = weighted mean effect size; s_g^2 = the observed variance of the effect sizes; s_e^2 = estimate of the variance in effect sizes due to sampling error; $s_\delta^2 = s_g^2 - s_e^2$ (residual variance); s_e^2/s_g^2 = proportion of observed variance due to sampling error; 95% CI = 95% confidence interval on $\bar{g}$; N = total number of participants across the k studies included in the analysis.
[a] Outliers removed. [b] The effect sizes within studies (i.e., those derived from the same sample of participants) are averaged prior to estimating means and variances. In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable.

Performance measures. Noise had a small-to-medium negative effect on accuracy ($g = -0.43$) and a very small but nonzero negative effect on response speed ($g = -0.14$). However, large observed variances were obtained for accuracy ($s_g^2 = 1.28$) and for speed ($s_g^2 = 1.24$), and outlier analyses were therefore performed for each case. For accuracy, seven outliers were identified. These were the studies by Barker and Cooke (2007); Enmarker, Boman, and Hygge (2006); Marsh, Hughes, and Jones (2009); Marsh, Vachon, and Jones (2008); Skowronski and Harris (2006); Weisz and Schlittmeier (2006), and Wong et al. (2009). For speed, three outliers were identified. These were the studies by Cassel and Dallenbach (1918) and Banbury and Berry (1998, Experiments 2 and 3). A reanalysis of the accuracy and speed data with the outliers removed resulted in smaller observed variances but did not substantially change the magnitude of the effects (see Table 1). It is also important to note that Cassel and Dallenbach's (1918) study used an N of only one.

Noise exposure schedule: Continuous versus intermittent. Exposure to intermittent noise ($g = -0.33$) was of a magnitude similar to that of continuous noise ($g = -0.26$). However, the observed variance associated with intermittent noise indicated the possibility of outliers. Analysis revealed five outliers. These were the studies by Banbury and Berry (1998, Experiment 2); Cassel and Dallenbach (1918); Chatterjee and Krishnamurty (1972); Lahtela, Niemi, Kuusela, and Hypen (1986); and Wong et al. (2009). Reanalysis with the outliers removed resulted in a smaller observed variance but only a slightly larger mean effect size (see Table 2). Note that there was minimal overlap in the CIs for continuous versus intermittent noise (after removal of outliers), indicating that intermittent noise is somewhat more damaging to performance than continuous noise.

Noise type. The effects on performance as a function of noise type are shown in Table 2. Speech noise was associated with a small-to-medium negative effect size ($g = -0.43$) and was more damaging to performance relative to nonspeech noise ($g = -0.16$) or music ($g = 0.09$, where zero was included in the 95% CI). However, the relatively large observed variances for the speech and nonspeech noise categories suggested the presence of outliers.

Subsequent analysis revealed seven outliers for the speech category: Banbury and Berry (1998, Experiment 2); Barker and Cooke (2007); Enmarker et al. (2006); Marsh, Vachon, and Jones (2008); Marsh et al. (2009); Meijer, de Groot, Van Boxtel, Van Gerven, and Jolles (2006); and Wong et al. (2009). Removal of these outliers substantially reduced the observed variance and also increased the magnitude of the mean effect size (see Table 2). For nonspeech noise, analysis revealed four outliers: Banbury and Berry (1998, Experiment 2); Cassel and Dallenbach (1918); Pollock, Bartlett, Weston, and Adams (1932); and Skowronski and Harris (2006). Removal of these outliers resulted in a smaller observed variance, but it did not substantially change the magnitude of the effect.

The magnitude of the effect for mixed speech/nonspeech ($g = -0.46$) was, logically enough, in between those of speech and nonspeech. At first, it appeared that music did not have a substantive effect on performance. However, this interpretation is limited by the small number of studies and the relatively large observed variance. Analysis here revealed one outlier, which was the study by Martin, Wogalter, and Forlano (1988, Experiment 3). Reanalysis without this outlier resulted in a substantially larger and positive effect size. However, this reduced the observed variance but resulted in a much larger error variance (see Table 2). Thus, the precise impact of music on performance has yet to be determined unequivocally at present.

Noise intensity. Studies in which the control condition consisted of lower decibel noise were considered separately from those in which the control condition consisted of a purported absence of noise, or a quiet condition. To simplify analysis and interpretation, studies were categorized as high or low in intensity according to the median split for the intensity of the experimental group or the difference in decibels between experimental and control conditions. The median intensity for the dB experimental-only group was 75 dB, whereas the median dB difference value was 30 dB.

For the studies in which noise was provided in both experimental and control conditions, higher intensity noise exposure was associated with a small-to-medium effect size ($g = -0.42$), whereas for lower intensity studies, the effect size was very small ($g = -0.12$; see Table 3). For those studies in which the control

Table 2
Noise Meta-Analysis Results by Noise Schedule and Type

Category	k^b	$\bar{g}$	s_g^2	s_e^2	s_δ^2	s_e^2/s_g^2	95% CI	N
Noise schedule								
Intermittent	131	−0.33	1.29	0.38	0.91	0.29	[$-0.43 < \delta < -0.22$]	8,017
Intermittent[a]	126	−0.39	0.75	0.35	0.40	0.47	[$-0.49 < \delta < -0.28$]	5,387
Continuous	120	−0.26	0.72	0.23	0.48	0.33	[$-0.34 < \delta < -0.17$]	6,387
Noise type								
Speech	124	−0.43	2.37	0.54	1.83	0.23	[$-0.56 < \delta < -0.30$]	6,882
Speech[a]	117	−0.84	0.56	0.78	—	—	[$-1.00 < \delta < -0.68$]	4,624
Nonspeech	124	−0.16	1.04	0.20	0.84	0.19	[$-0.24 < \delta < -0.08$]	7,784
Nonspeech[a]	120	−0.20	0.41	0.17	0.25	0.40	[$-0.28 < \delta < -0.13$]	7,733
Mix (speech and nonspeech)	13	−0.46	0.31	0.21	0.09	0.70	[$-0.72 < \delta < -0.21$]	477
Music	6	0.09	1.86	0.16	1.70	0.09	[$-0.23 < \delta < 0.041$]	162
Music[a]	5	0.71	0.48	9.68	—	—	[$-2.02 < \delta < 3.44$]	138

Note. k = number of studies included in the analysis; $\bar{g}$ = weighted mean effect size; s_g^2 = the observed variance of the effect sizes; s_e^2 = estimate of the variance in effect sizes due to sampling error; $s_\delta^2 = s_g^2 - s_e^2$ (residual variance); s_e^2/s_g^2 = proportion of observed variance due to sampling error; 95% CI = 95% confidence interval on $\bar{g}$; N = total number of participants across the k studies included in the analysis.
[a] Outliers removed. [b] The effect sizes within studies (i.e., those derived from the same sample of participants) are averaged prior to estimating means and variances. In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable.

Table 3
Noise Meta-Analysis Results for Intensity and Duration of Exposure

Intensity	k^b	$\bar{g}$	s_g^2	s_e^2	s_δ^2	s_e^2/s_g^2	95% CI	N
				dB experimental				
Low	71	−0.35	1.67	0.31	1.36	0.19	[−0.48 < δ < −0.22]	2,980
Low[a]	66	−0.65	0.30	0.40	—	—	[−0.81 < δ < −0.50]	2,513
High	91	−0.16	0.37	0.17	0.20	0.45	[−0.24 < δ < −0.07]	5,954
				dB difference				
Low	58	−0.12	0.42	0.15	0.26	0.37	[−0.22 < δ < −0.02]	1,912
High	33	−0.42	0.36	0.16	0.20	0.45	[−0.55 < δ < −0.28]	1,304
				Duration				
Short	67	−0.70	0.62	0.55	0.07	0.88	[−0.88 < δ < −0.53]	2,800
Long	52	−0.28	0.35	0.22	0.13	0.62	[−0.41 < δ < −0.16]	1,996

Note. k = number of studies included in the analysis; $\bar{g}$ = weighted mean effect size; s_g^2 = the observed variance of the effect sizes; s_e^2 = estimate of the variance in effect sizes due to sampling error; $s_\delta^2 = s_g^2 - s_e^2$ (residual variance); s_e^2/s_g^2 = proportion of observed variance due to sampling error; 95% CI = 95% confidence interval on $\bar{g}$; N = total number of participants across the k studies included in the analysis.
[a] Outliers removed. [b] The effect sizes within studies (i.e., those derived from the same sample of participants) are averaged prior to estimating means and variances. In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable.

condition did not include noise, lower intensity was associated with a small-to-medium negative effect ($g = -0.35$) relative to higher intensity exposure ($g = -0.16$). However, the observed variance for the low-intensity category was relatively large. Analysis indicated five outliers: Banbury and Berry (1998, Experiments 2 and 3); Enmarker et al. (2006); Hygge and Knez (2001); and Skowronski and Harris (2006). Removal of the outliers resulted in a larger mean effect size but a substantially smaller observed variance (see Table 3).

Duration. The moderation of noise effects by duration of exposure was analyzed by dividing the duration categories by means of a median split. The median duration was 1.1 min. For relatively short duration exposures, a medium-to-large effect size was obtained ($g = -0.70$), whereas a small effect size was observed at longer durations ($g = -0.28$; see Table 3), and the CIs for the two durations did not overlap. Hence, noise has more negative effects on performance at relatively short durations of exposure, whereas at longer durations the effect is attenuated. This effect may perhaps be due to the capacity of individuals to adapt to the noise stress (see later discussion).

Joint Effects of Two Moderator Variables

Task Category × Measure. Results of the moderator analysis of task category within each dependent measure category are shown in Table 4 and Figure 6. Twenty-four studies examined noise effects on the accuracy of performance in perception, yielding a weak effect ($g = -0.06$). Twenty studies assessed noise effects on the speed of response in perception tasks, but again, no substantial effect was found ($g = 0.06$). The lack of effect of noise

Table 4
Moderator Analysis of Task Category Within Each Dependent Measure Category

Dependent variable/task	k^b	$\bar{g}$	s_g^2	s_e^2	s_δ^2	s_e^2/s_g^2	95% CI	N
Accuracy								
Perceptual	24	−0.06	0.23	0.10	0.12	0.45	[−0.19 < δ < 0.07]	1,057
Cognitive	179	−0.50	1.57	0.38	1.19	0.24	[−0.59 < δ < −0.41]	9,085
Cognitive[a]	172	−0.57	0.76	0.35	0.41	0.46	[−0.66 < δ < −0.48]	8,629
Motor	8	−0.51	0.30	0.14	0.16	0.46	[−0.77 < δ < −0.25]	310
Communication	15	−0.64	0.20	0.79	—	—	[−1.08 < δ < −0.19]	475
Speed								
Perceptual	20	0.06	0.72	0.17	0.54	0.24	[−0.12 < δ < 0.24]	3,324
Cognitive	24	0.35	6.85	0.17	6.68	0.02	[0.19 < δ < 0.52]	870
Cognitive[a]	22	0.11	0.54	0.15	0.39	0.28	[−0.05 < δ < 0.27]	822
Motor	3	0.13	0.65	0.28	0.37	0.43	[−0.46 < δ < 0.72]	81
Communication	2	−0.23	Davies & Davies (1975) $g = -0.41$; Van Gemmert & Van Galen (1997) $g = 0.65$					

Note. k = number of studies included in the analysis; $\bar{g}$ = weighted mean effect size; s_g^2 = the observed variance of the effect sizes; s_e^2 = estimate of the variance in effect sizes due to sampling error; $s_\delta^2 = s_g^2 - s_e^2$ (residual variance); s_e^2/s_g^2 = proportion of observed variance due to sampling error; 95% CI = 95% confidence interval on $\bar{g}$; N = total number of participants across the k studies included in the analysis.
[a] Outliers removed. [b] The effect sizes within studies (i.e., those derived from the same sample of participants) are averaged prior to estimating means and variances. In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable.

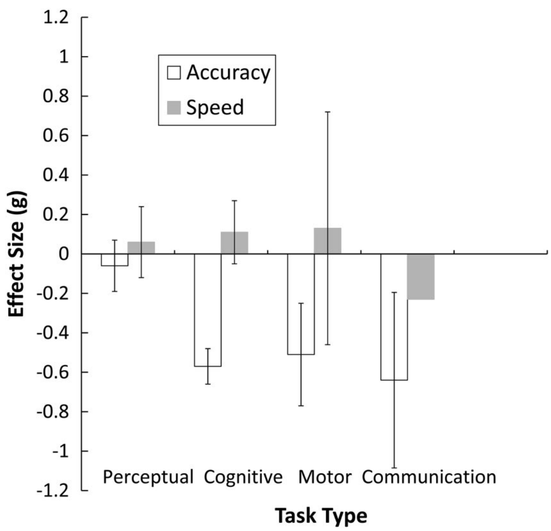

Figure 6. Mean effect size as a function of task category for accuracy and speed. Error bars are 95% confidence intervals.

on the speed or accuracy of these responses is not surprising given the lack of observed effect on perception tasks as a whole. Our present analysis does, however, argue against a speed–accuracy trade-off being responsible for the absence of a substantial overall effect. As indicated earlier, there are likely to be other moderating variables influencing the overall effect size, as is evident from the proportion of variance accounted for by sampling error.

Most of the studies examining noise effects on the performance of cognitive tasks used dependent variables based on the accuracy of response ($k = 179$) relative to those using speed of response ($k = 24$). Noise was found to degrade accuracy (a medium effect, $g = -0.50$) but actually turned out to facilitate speed of response (a small effect, $g = 0.35$; see Table 4). The 95% CI for these respective effects did not contain zero. However, consideration of the unusually large total variance for both accuracy and speed suggested the presence of outliers. There were seven outliers for accuracy: Barker and Cooke (2007); Enmarker et al. (2006); Marsh, Vachon, and Jones (2008); Marsh et al. (2009); Skowronski and Harris (2006); Weisz and Schlittmeier (2006), and Wong et al. (2009). For speed, there were two outlier studies: Banbury and Berry (1998, Experiments 2 and 3). Removal of these outliers did not substantially affect the results for accuracy, but it did substantially change the results for speed of performance in cognitive tasks. As can be seen in Table 4, removal of outliers reduced the observed variance, but it also reduced the mean effect size, such that the subsequent CI did contain zero.

As might be expected, fewer studies examined motor performance compared with cognitive performance. Eight studies examined the accuracy of response for motor tasks, whereas only three studies assessed the speed of response. Accuracy was found to be degraded by noise (medium effect, $g = -0.51$). Speed of response was associated with a small effect size ($g = 0.13$), and the 95% CI contained zero. These two results must be considered with caution, however, because of the small number of studies involved. The accuracy and speed effects for the communication category were also drawn from relatively few studies. Fifteen studies used accuracy measures for communication, yielding a medium-to-large negative effect ($g = -0.64$), but only two studies measured speed, with effect sizes in opposite directions ($g = 0.65$ and $g = -0.41$, respectively; see Table 4).

Noise Schedule × Noise Type. A summary of the analysis of noise effects as a function of noise schedule (continuous vs. intermittent) within each type of noise is shown in Table 5 and graphically depicted in Figure 7. Intermittent noise did not sub-

Table 5
Summary Results for Schedule × Noise Type

Schedule	k^b	$\bar{g}$	s_g^2	s_e^2	s_δ^2	s_e^2/s_g^2	95% CI	N
				Nonspeech				
Intermittent	39	0.06	1.36	0.16	1.19	0.12	[−0.07 < δ < 0.19]	4,597
Intermittent[a]	37	−0.07	0.53	0.14	0.39	0.27	[−0.19 < δ < 0.05]	4,572
Continuous	91	−0.24	0.70	0.22	0.49	0.31	[−0.34 < δ < −0.15]	3,592
				Speech				
Intermittent	101	−0.80	1.29	0.80	0.49	0.62	[−0.97 < δ < −0.63]	3,948
Intermittent[a]	95	−0.83	0.26	0.78	—	—	[−1.01 < δ < −0.65]	3,657
Continuous	16	−0.32	0.09	0.91	—	—	[−0.79 < δ < 0.15]	660
				Mix				
Intermittent	3	−0.48	6.53	0.28	6.25	0.04	[−1.08 < δ < 0.13]	136
Continuous	10	−0.56	0.17	0.30	—	—	[−0.90 < δ < −0.21]	336
				Music				
Intermittent	2	1.5	Davenport (1972) Experiment 1A, $g = 1.53$; Experiment 1B, $g = 1.48$					48
Continuous	4	−0.67	1.64	7.49	—	—	[−3.35 < δ < 2.02]	114

Note. k = number of studies included in the analysis; $\bar{g}$ = weighted mean effect size; s_g^2 = the observed variance of the effect sizes; s_e^2 = estimate of the variance in effect sizes due to sampling error; $s_\delta^2 = s_g^2 - s_e^2$ (residual variance); s_e^2/s_g^2 = proportion of observed variance due to sampling error; 95% CI = 95% confidence interval on $\bar{g}$; N = total number of participants across the k studies included in the analysis.
[a] Outliers removed. [b] The effect sizes within studies (i.e., those derived from the same sample of participants) are averaged prior to estimating means and variances. In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable.

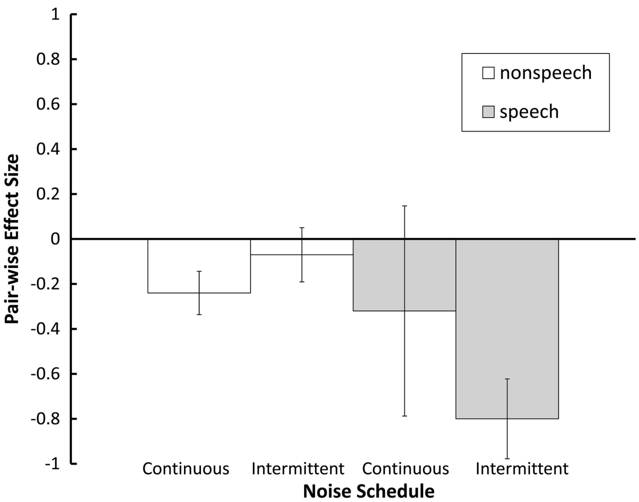

Figure 7. Mean effect size as a function of noise schedule for nonspeech and speech noise. Error bars are 95% confidence intervals.

stantially influence performance when nonspeech or a mix of speech and nonspeech were used. However, intermittent speech noise exerted a large negative effect on performance ($g = -0.80$). In contrast, music had a large facilitative effect on performance ($g = 1.5$). However, this latter result is founded on only two studies. Continuous speech noise was associated with a small negative effect, but the CI contained zero. Nonspeech continuous noise was associated with a small but meaningful effect ($g = -0.24$), and a mix of speech and nonspeech noise was associated with a deleterious medium effect ($g = -0.56$). Continuous music was associated with a large negative effect, but the sampling error variance was also large.

Outlier analyses. As can be seen in Table 5, there were four categories with relatively large observed variances for the intermittent speech and nonspeech categories. Outlier analyses were computed for each case. For the intermittent nonspeech noise category, two outliers were identified: Cassel and Dallenbach (1918) and Banbury and Berry (1998, Experiment 2). Removal of these outliers reduced the observed variance but had little effect on the magnitude of the effect size, as the CI contained zero. For intermittent speech noise, analysis indicated the presence of six outliers: Banbury and Berry (1998, Experiments 2 and 3); LeCompte and Shaibe (1997, Experiment 5); Mech (1953); Colle and Welsh (1976, Experiment 1); and Wong et al. (2009). However, removal of these outliers did not substantially change the mean effect size or the interpretation. It did, however, substantially reduce the observed variance.

The observed variance for intermittent mixed noise was rather large, but there were only three studies involved here. In one case, the effect size was very large (Chatterjee & Krishnamurty, 1972, $g = -7.64$) relative to the other two (Knez & Hygge, 2002, $g = -0.48$; Salamé & Wittersheim, 1978, $g = -0.98$). Similarly, of the four studies that examined the effects of continuous music, one exhibited a large effect size (Martin et al., 1988, Experiment 3, $g = -2.75$) relative to the other three (Van Gemmert & van Galen, 1997, $g = 0.17$; Martin, Wogalter, & Forlano, 1988, Experiment 1, $g = 0.06$, and Experiment 2, $g = 0.07$). Hence, with the exception of one study, continuous music did not substantially impact performance.

Intensity × Duration. According to the maximal adaptability stress theory (Hancock & Warm, 1989), the intensity and duration of exposure to a stressor should interact directly to influence performance. To evaluate this proposition, moderator analyses were computed for noise intensity within each level of duration. Two separate analyses were computed: (a) dB difference between experimental and control conditions for those studies in which the control group dB was reported and (b) dB of the experimental-only condition in cases in which the control condition consisted of the reported absence of noise or the dB of the control condition was not explicitly specified.

Short duration/dB experimental only. At short durations, low-intensity noise negatively influenced performance ($g = -1.58$), a large effect. At high intensity, the effect size was small ($g = -0.26$), but the 95% CI did not contain zero (see Table 6 and Figure 8).

Long duration/dB experimental only. At long durations and low intensities, a small effect was observed ($g = -0.37$), and a slightly smaller negative effect was obtained at higher intensity ($g = -0.30$; see Table 6 and Figure 8).

Short duration/dB difference. The results for this analysis are shown in Table 6 and Figure 9. At short durations and lower intensities, differences between experimental and control groups are represented by only three studies. Here, the effect size was actually medium and positive ($g = 0.63$). However, as might be expected with so few studies, the 95% CI contained zero. Of the three studies, one (Breen-Lewis & Wilding, 1984, $g = 0.67$) had an effect size substantially smaller than the other two and in the opposite direction (Breen-Lewis & Wilding, 1984, $g = -1.20$; Campbell, Beaman, & Berry, 2002a, Experiment 2, $g = -1.66$). For studies with large differences between experimental and control condition, a medium-to-large negative effect was observed ($g = -0.68$), and the 95% CI did not contain zero.

Long duration/dB difference. At longer durations and lower intensities, a negligible effect size was observed ($g = 0.03$), whereas at larger differences a medium-to-large effect size was observed ($g = -0.66$).

Duration × Schedule. For continuous noise, a stronger negative effect was observed at longer durations relative to shorter durations, although both effect sizes were relatively small and the CI for the short duration effect contained zero (see Table 7 and Figure 10). For intermittent noise, shorter durations were associated with a slightly stronger negative effect on performance, but inspection of the CIs indicates that these two effects are of similar magnitudes.

Task × Noise Type. For speech, there were no studies in the psychomotor or communication categories and only four studies using a perceptual task. However, large effect sizes were observed for the latter category and for cognitive tasks (after the following outliers were removed: Banbury & Berry, 1998, Experiment 2; Barker & Cooke, 2007; Enmarker et al., 2006; Marsh, Hughes, & Jones, 2008; Marsh et al., 2009; Meijer et al., 2006; Wong et al., 2009). For the psychomotor tasks one outlier was identified (Pollock, Bartlett, Weston, & Adams, 1932), and for the communication category, there were two outliers (Boggs & Simon, 1988; Smith, 1985a). In contrast, nonspeech noise was associated with very small effects in these

Table 6
Summary Results for Intensity × Duration

Duration and intensity	k^a	$\bar{g}$	s_g^2	s_e^2	s_δ^2	s_e^2/s_g^2	95% CI	N
				dB experimental				
Short duration								
Low	26	−1.58	0.78	0.79	—	—	[−1.92 < δ < −1.24]	932
High	14	−0.26	0.28	0.19	0.10	0.65	[−0.49 < δ < −0.04]	699
Long duration								
Low	10	−0.37	0.18	0.10	0.08	0.55	[−0.56 < δ < −0.17]	509
High	37	−0.30	0.43	0.21	0.23	0.47	[−0.45 < δ < −0.16]	1,350
				dB difference				
Short duration								
Low	3	0.63	1.93	0.34	1.59	0.17	[−0.02 < δ < 1.29]	88
High	6	−0.68	0.01	0.12	—	—	[−0.96 < δ < −0.40]	310
Long duration								
Low	20	0.03	0.45	0.15	0.30	0.34	[−0.14 < δ < 0.20]	759
High	15	−0.66	0.12	0.26	—	—	[−0.92 < δ < −0.41]	480

Note. k = number of studies included in the analysis; $\bar{g}$ = weighted mean effect size; s_g^2 = the observed variance of the effect sizes; s_e^2 = estimate of the variance in effect sizes due to sampling error; $s_\delta^2 = s_g^2 - s_e^2$ (residual variance); s_e^2/s_g^2 = proportion of observed variance due to sampling error; 95% CI = 95% confidence interval on $\bar{g}$; N = total number of participants across the k studies included in the analysis.
[a] The effect sizes within studies (i.e., those derived from the same sample of participants) are averaged prior to estimating means and variances. In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable.

categories and with medium negative effects on psychomotor and communication tasks (see Table 8 and Figure 11). With respect to the perceptual and cognitive categories, the effects were small even after removal of one outlier for the former (Cassel & Dallenbach, 1918) and two outliers for the latter (Banbury & Berry, 1998, Experiment 2; Skowronski & Harris, 2006). Note that the results reported here are restricted to the speech and nonspeech categories of noise type because of the limited number of studies that used mixed speech/nonspeech or music.

Essentially, the preceding results consist of the main effects and first-order interactions for and between major moderators. The current meta-analysis permits some assessment of nominal second-order interactions. However, because our primary concern is with how the major patterns of effect are reflected in major theoretical positions, we have not included these latter results in the published work but have reported them for completeness in the supplemental materials.

Discussion

The goals for the present meta-analytic review were to provide quantitative estimates of the effects of noise on performance and to estimate the moderating influence of task characteristics and of

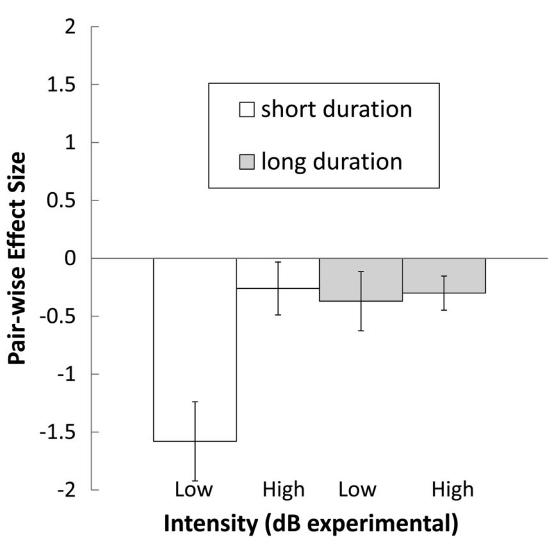

Figure 8. Mean effect size as a function of intensity (dB experimental) and duration of exposure. Error bars are 95% confidence intervals.

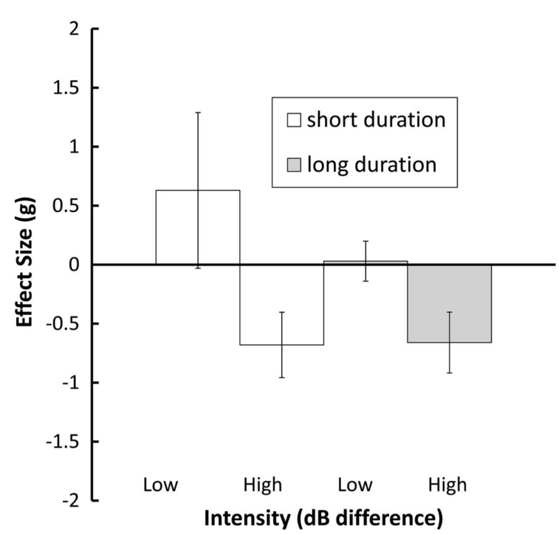

Figure 9. Mean effect size as a function of intensity (dB difference) and duration of exposure. Error bars are 95% confidence intervals.

Table 7
Summary Results for Duration × Schedule

Schedule	k^a	$\bar{g}$	s_g^2	s_e^2	s_δ^2	s_e^2/s_g^2	95% CI	N
Intermittent								
Short	65	−0.79	0.52	0.62	—	—	[$-0.99 < \delta < -0.60$]	2,720
Long	6	−0.70	0.06	0.52	—	—	[$-1.28 < \delta < -0.12$]	237
Continuous								
Short	4	−0.14	0.78	0.22	0.56	0.28	[$-0.59 < \delta < 0.32$]	196
Long	46	−0.24	0.36	0.19	0.17	0.52	[$-0.37 < \delta < -0.12$]	1,759

Note. k = number of studies included in the analysis; $\bar{g}$ = weighted mean effect size; s_g^2 = the observed variance of the effect sizes; s_e^2 = estimate of the variance in effect sizes due to sampling error; $s_\delta^2 = s_g^2 - s_e^2$ (residual variance); s_e^2/s_g^2 = proportion of observed variance due to sampling error; 95% CI = 95% confidence interval on $\bar{g}$; N = total number of participants across the k studies included in the analysis.
[a] The effect sizes within studies (i.e., those derived from the same sample of participants) are averaged prior to estimating means and variances. In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable.

spatial, temporal, and content characteristics of the noise itself. The present results illustrate that noise does have a deleterious effect of small-to-medium magnitude on performance capacity. However, one should not then conclude that all noise has uniformly deleterious effects on all types of task performance. Rather, the magnitudes of noise effects varied widely as a function of noise intensity, its duration, the schedule of exposure, the precise form of noise, and the type of task undertaken as well as the performance measures used to assess it.

Noise generally has only a small effect on the performance of perceptual tasks, except in the case of speech noise (see Table 8). This latter effect may be related to greater interference of speech because of the distracting nature of that form of stimulus, an interpretation that would be consistent with the perspective that noise exerts its effects through the information it provides the individual (Hancock & Warm, 1989; Jones, 1993; Macken et al., 2009). Psychomotor and communication tasks suffered medium-level negative effects, although hierarchical analyses indicated that this trend was stronger for measures of response accuracy than it was for measures of response speed. Consistent with the resource-based maximal adaptability theory, accuracy in cognitive and communication tasks was most vulnerable to noise effects. With respect to the cognitive tasks, deleterious effects were relatively high when the noise was composed of speech. There was little evidence of any speed–accuracy trade-off across task types or within task categories. In general, when effects were observed, they were stronger for response accuracy compared with response speed.

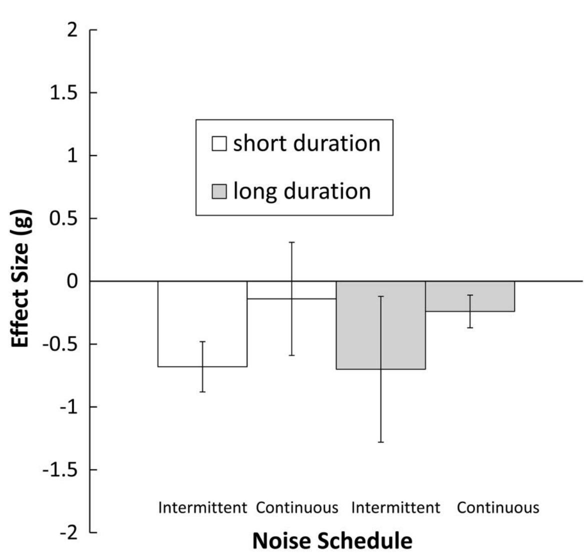

Figure 10. Mean effect size as a function of noise duration and schedule. Error bars are 95% confidence intervals.

With respect to the effect of acoustic noise on psychomotor performance, the interpretation of the results is constrained by the limited number of studies using such tasks. This outcome serves to underscore the fact that more research is needed in certain specific areas before any definitive conclusion can be drawn and points to an issue we have raised before (Hancock et al., 2007); that is, it is often considered understood and accepted knowledge that a particular form of stress degrades performance. Thus, researchers are averse to conducting studies on supposedly known effects. However, as is clear in the present analysis, a careful perusal of the literature shows that such studies have not been conducted, and the assumption may be based on expectation rather than observed data. The present article serves to highlight where such cases occur specifically in the noise literature.

The Occupational Safety and Health Administration (1983) regulates the maximum duration of exposure to high-decibel continuous noise. The present study confirms that continuous nonspeech noise is somewhat more debilitating than intermittent nonspeech noise, although the overall magnitude of the effect was small (Table 5). However, the present results also indicate that intermittent schedules of speech noise are more debilitating to performance than continuous noise. Thus, particular forms of current exposure limits may themselves be incomplete, especially when protecting individuals in performance-critical occupations.

These findings confirm (for speech noise) the claim of previous researchers (e.g., Loeb, 1986) that intermittent noise proves to be the more disruptive type of noise. Loeb (1986) further argued that intermittent noise is more damaging to performance (a) because there is less opportunity for behavioral habituation and (b) because it is the *change* in decibel level of the noise (e.g., change from quiet to noise) rather than dB level per se that is the casual influence. This proposition was confirmed in the present pattern of meta-analytic results. That is, when reliable negative performance effects were observed, intermittent noise was generally associated

Table 8
Summary Results for Task Category Within Each Noise Type Category

Task/noise type	k^b	$\bar{g}$	s_g^2	s_e^2	s_δ^2	s_e^2/s_g^2	95% CI	N
Speech								
Perceptual	4	−0.74	0.03	0.28	—	—	[−1.26 < δ < −0.22]	174
Cognitive	117	−0.43	2.19	0.53	2.19	0.19	[−0.57 < δ < −0.30]	6,675
Cognitive[a]	110	−0.84	0.58	0.74	—	—	[−1.00 < δ < −0.68]	4,417
Motor	0							
Communication	0							
Nonspeech								
Perceptual	33	0.02	0.26	0.13	0.13	0.50	[−0.10 < δ < 0.14]	3,900
Perceptual[a]	32	−0.20	0.13	0.03	0.11	0.19	[−0.26 < δ < −0.15]	3,899
Cognitive	85	−0.14	1.36	0.21	1.15	0.16	[−0.24 < δ < −0.04]	3,736
Cognitive[a]	83	−0.21	0.61	0.19	0.42	0.31	[−0.31 < δ < −0.12]	3,687
Motor	10	−0.51	0.09	0.21	—	—	[−0.79 < δ < −0.22]	327
Motor[a]	9	−0.49	0.21	0.17	0.04	0.81	[−0.76 < δ < −0.22]	326
Communication	7	−0.43	0.05	0.22	—	—	[−0.77 < δ < −0.08]	298
Communication[a]	5	−0.43	0.03	0.16	—	—	[−0.77 < δ < −0.08]	210

Note. k = number of studies included in the analysis; $\bar{g}$ = weighted mean effect size; s_g^2 = the observed variance of the effect sizes; s_e^2 = estimate of the variance in effect sizes due to sampling error; $s_\delta^2 = s_g^2 - s_e^2$ (residual variance); s_e^2/s_g^2 = proportion of observed variance due to sampling error; 95% CI = 95% confidence interval on $\bar{g}$; N = total number of participants across the k studies included in the analysis.
[a] Outliers removed. [b] The effect sizes within studies (i.e., those derived from the same sample of participants) are averaged prior to estimating means and variances. In the moderator analyses, this averaging procedure was conducted within each level of the moderator variable.

with a larger effect size than continuous noise. Future programmatic research efforts should therefore seek to systematically manipulate the temporal properties of intermittent noise to specifically and quantitatively address the role of the schedule of intensity change on performance capacity. Furthermore, regulatory bodies need to give more attention to the effects of intermittent noise, especially as behavioral markers, such as performance change, can give early evidence of damaging health effects (see Hancock & Vastmizidis, 1998).

In addition to the schedule of presentation, the type of noise was an important moderating variable. In general, irrelevant speech was more disruptive than nonspeech, mixed speech/nonspeech, or music. Indeed, in some instances (e.g., Van Gemmert & Van Galen, 1997) music actually facilitated performance. However, very few studies have examined the performance effects of music as distracting noise. This omission was noted over two decades ago by Loeb (1986). This stands as an important omission, especially in light of the modern proliferation of handheld music devices that have made listening to music a potential distracter in a wide range of important occupational circumstances and performance-critical situations. It is therefore important to identify this issue as a crucial societal concern to be addressed by future research.

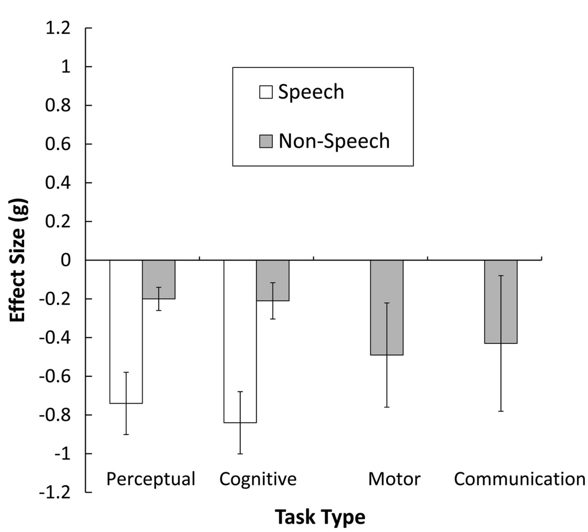

Figure 11. Mean effect size as a function of task category for nonspeech and speech noise. Error bars are 95% confidence intervals.

The stronger effects associated with irrelevant speech relative to other forms of noise suggest that the debilitating effect may come primarily from the distraction away from the task, with irrelevant speech thereby competing for the same attentional resource capacities (Wickens, 2002). This interpretation is supported by the fact that the negative effect of speech was stronger when the schedule was intermittent rather than continuous. Indeed, this parallel problem may pervade the crucial social issue of distracted driving (Hancock, Mouloua, & Senders, 2008) and especially problems associated with cell-phone use in vehicles (Caird, Willness, Steel, & Scialfa, 2008; Lesch & Hancock, 2004). It may be that in continuous noise, individuals can adapt to the speech (e.g., habituate to it or learn to ignore it) and thereby reduce its demands on cognitive resources. In contrast, intermittent noise may be more difficult to ignore, thereby making adaptation more difficult to achieve when the noise has meaningful but task irrelevant content. This may also be why speech noise had a stronger effect on cognitive and communication tasks relative to other task categories.

Shorter durations proved more debilitating to performance than longer durations. Such a finding is in contrast to the argument that short-duration exposure may facilitate performance because of the transient arousing effects of noise that can temporarily increase information-processing resources (Broadbent, 1978; Helton, Warm, Matthews, Corcoran, & Dember, 2002; Poulton, 1976, 1977). One possible reason for the general negative effect of short-duration noise is that at longer durations, individuals may develop effective coping strategies that allow them to adapt to the noise. In contrast, in shorter durations of exposure, there may be a very limited opportunity for such adaptation to occur. Again, this postulate is deserving of further experimental and modeling evaluation.

Low-intensity noise was more debilitating than high-intensity noise for those studies in which the control condition consisted of the nominal absence of noise, or quiet. This pattern was reversed for those studies in which two levels of intensity were compared. These results were contrary to predictions based on the composite theory, which predicted strong negative effects of high- versus low-intensity noise relative to a quiet control condition. Apparently, the negative effects of noise intensity depend, in part, on the nature of the control condition (quiet vs. lower dB noise). Future research should therefore consider the regular use of at least both of these two comparative control conditions (i.e., quiet and a lower intensity noise).

The pattern of results for intensity may have implications for understanding the unexpected duration effect. The greater performance impairment at lower durations of noise exposure was observed only at lower intensities and in studies in which the control condition consisted of the nominal absence of noise (i.e., a quiet condition; see Table 6). This pattern was not observed when the control condition consisted of a lower intensity noise. The duration results may thus result from differences across studies in the intensity of acoustic stimulation in the comparison group. Future studies should therefore precisely specify the decibel level of the control group even when performance in the presence of noise is compared with a quiet condition.

Implications of the Meta-Analytic Results for the Three Theories

Arousal theory. The meta-analytic results provide only very mixed evidence in support of the unitary arousal theory. Consistent with predictions from arousal theory, cognitive and communication tasks did prove more vulnerable to noise impairment than perceptual or motor tasks, and accuracy was more impaired than speed. However, contrary to the predictions of arousal theory, there were differences as a function of noise type and schedule, such that the intermittent/continuous distinction had relatively little impact on nonspeech noise but were substantially different for speech. Perhaps more damaging to the case for arousal theory is that the duration effect was in the opposite direction from that expected: Shorter durations impaired performance more than longer exposures. Effects of intensity and Intensity × Duration were consistent with arousal theory but only for those studies in which the control group consisted of a lower intensity of noise. For those studies in which the control group consisted of the nominal absence of noise, lower intensities were more debilitating—a pattern that was inconsistent with all three theories.

The limited support for unitary arousal theory was not surprising, given that this perspective has proved to have serious limitations (Hancock & Ganey, 2003; Hockey, 1984). Although there is evidence of an association between arousal and attention related to a dopamine-mediated stochastic process (Sikström & Soderlund, 2007), the notion of a unitary arousal mechanism underlying all human performance under stress does not adequately account for the complexity of effects. For instance, Hockey and Hamilton (1983) proposed that the effects of stressors on performance can be differentiated by their cognitive patterning and that a single mechanism explanation is therefore unlikely to adequately explain such complex interactive stress effects. In a review of noise effects, Holding and Baker (1987) argued that the evidence indicated that "systematic interactive effects are not due to [a] simple arousal explanation" (p. 399). They interpreted the inconsistencies in noise effects as due to the tendency of researchers to search for broad generalization of noise effects rather than for specific interactive effects. The present analysis supports this latter view. However, from a dual-arousal perspective (e.g., Thayer, 1978, 1989), it is possible that the effects of noise differ for energetic versus tense arousal (e.g., Helton, Matthews, & Warm, 2009). Such effects could not be evaluated in the present meta-analysis, but this pattern does indicate a need for future empirical research to test a dual arousal model.

Composite theory. The results of the meta-analysis support Poulton's (1981a) argument that accuracy is more vulnerable to impairment than speed. However, our findings do not support a masking-of-inner-speech effect (see Poulton, 1979), as such effects should occur regardless of noise or task type. Further, contrary to such a prediction, greater impairment was observed at shorter durations relative to longer durations. This latter finding is in direct conflict with the arousal/masking mechanism of the composite theory.

Maximal adaptability theory. Predictions from the maximal adaptability model fit the majority of the findings of the present analysis. The negative effect of speech versus nonspeech is particularly instructive, because it is inconsistent with both unitary arousal theory (Broadbent, 1978) and the masking of inner speech, which was the hallmark of composite theory (Poulton, 1979). Both of these theories predict that the content of the noise would not be expected to exert an effect. That is, noise should increase arousal or mask inner speech regardless of whether the noise is speech or nonspeech. However, the meta-analytic results indicate that speech is much more disruptive to performance than nonspeech noise. The problem for Poulton's (1979) argument is not masking per se but the lack of clarity regarding the definition of inner speech. If taken literally, one would expect that tasks requiring communication would be most disrupted, but this was not supported by the results of the present study. Further, the masking of inner speech (essentially a reduction in the signal-to-noise ratio) should be greater at higher intensities, but as noted earlier, this was not observed. The differences between speech and nonspeech effects could be explained in terms of masking if one assumes that content similar to the inner speech is more disruptive. However, in this case, inner speech would be defined as a cognitive process akin to a resource. It is not clear how Poulton's composite model differentiates masking in terms of a reduction of the signal-to-noise ratio of information to be processed from an attentional mechanism in which the noise diverts resources away from task-related information processing.

Given the problems with unitary arousal theory, the controversy over masking of inner speech, and the fact that the results of this meta-analytic review are inconsistent with both of these latter explanations, an energetic resource model of stress and performance may well be more appropriate in explaining the extant pattern of noise effects. For instance, the findings with respect to duration of exposure may be related to insufficient time to develop effective strategies for compensatory effort allocation; yet, at longer durations, such skills can develop, and adaptation is more likely. With respect to noise type, speech noise should be more disruptive than nonspeech because such stimulation should be more likely to compete with information-processing resources also needed for effective task performance (Wickens, 2002). Hence, it may be that the facilitative effects of noise occur through an energetic arousal mediated recruitment of compensatory resources and the allocation of those capacities to maintaining performance (Hancock & Warm, 1989; Hockey, 1997; Kahneman, 1973). Deleterious effects occur because of the joint effects of task demands and noise on effective adaptation or coping (Hancock & Warm, 1989), on changes in energetic and tense arousal (Helton, Shaw, Warm, Matthews, & Hancock, 2008; Thayer, 1989), and on the depletion of available processing capacity to maintain task effort (Cohen & Spacapan, 1978; Hockey, 1997). In general, the research literature has largely neglected the role of compensatory effort and coping in the relationship between noise and performance, so this interpretation should also be addressed and clarified in future empirical work.

An energetic/resource explanation has received recent support from evidence indicating that the effects of noise on performance may be mediated by the cognitive state of the individual. Helton et al. (2009) tested this possibility in the context of a sustained attention task. They reported that the facilitative effect of noise on a short duration vigilance task was mediated by the level of task engagement of the individual, a state composed of energetic arousal, motivation, and concentration that reflects a core relational theme (Lazarus, 1999) of commitment to effort (Matthews et al., 2002). If supported by future findings on a variety of tasks and noise characteristics (type, schedule, etc.), this approach could clarify the noise effects proposed by different theories. For instance, in vigilance tasks, noise may facilitate performance by increasing energetic arousal and resource capacity because it adds stimulation to a relatively unstimulating task. In contrast, on more complex cognitive tasks, noise may impair performance because of failures of attention (e.g., to notice events; De Coensel et al., 2009), disruptions in working memory processing (Jones, 1993; Macken et al., 2009), or reduction in resource capacity due to compensatory response (Hancock & Warm, 1989; Hockey, 1997). With respect to these potential mechanisms, future empirical efforts should programmatically investigate the structural versus the strategic effects of noise (Hockey, 1997).

If noise exerts its effects through affecting (a) resource capacity and (b) strategic allocation of resources (e.g., coping, compensatory effort), then one implication of the maximal adaptability theory is that any one moderator variable is unlikely to show homogeneous effects. Rather, multivariate interactions are likely to predominate. The potential for such joint effects is not a new idea, as Loeb (1981, 1986) identified the complexity of noise effects and the dependence on task type and form of noise almost 30 years ago. This complexity may be responsible for the inconsistencies in the intensity results, depending on intensity manipulation at short versus long durations (cf. Table 3 vs. Table 6). In general, intensity proves less important for noise than it is for other physical stressors, such as thermal exposure (Hancock et al., 2007) and vibration (Conway et al., 2007), possibly because noise intensity may not influence resource capacity to the same extent as the type and schedule of noise. This anomaly may well result from noise being a relatively new stress in evolutionary terms. Of course, this does not mean that high-intensity noise has no impact on health and well-being or that it does not require regulation in operational settings. Rather, the current results indicate that the derivation of guidelines for controlling noise in mitigation efforts is likely to be successful in protecting performance only if other contextual characteristics are considered. However, we have demonstrated clearly that the empirical research that permits anything more than speculative conclusions regarding a number of these joint interactive effects (Hancock & Szalma, 2008) has been extremely limited. Eventual resolution of the theoretical issues will require that the evident empirical gaps be filled with programmatic empirical research findings.

In our previous meta-analytic reviews (Conway et al., 2007; Hancock et al., 2007), the intensity and duration of the physical stressor proved to be key moderating variables. These can be interpreted as forms of information structure and information rate, respectively. Information structure refers to the organization of task elements; it is spatial in character. In the context of the present study and our previous meta-analytic reviews, intensity refers to the amplitude of vibration, sound waves, or kinetic energy (temperature) and is thus primarily a spatial feature. In the maximal adaptability model, information rate and information structure are necessarily contingent dimensions. Thus, one cannot have a structure without a necessary temporal component and, in parallel, rate cannot exist without any form of accompanying structure. Intensity proves to be a pertinent illustration of this necessary relationship. Here, the temporal dimension of frequency (e.g., oscillations per second) emphasizes the rate aspect of the model, and in a comparable fashion, its amplitude reflects the information structure component of the model. This latter characteristic illustrates the varying degree to which information structure is resident in the environment. For instance, pure tones contain minimal informational structure for the human observer, whereas more complicated amplitude patterns (e.g., speech) represent a much greater degree of information structure for the human listener. For other animals, human speech contains comparatively less information but is still far from meaningless noise.

In the case of noise, intensity and duration variables did moderate stress effects, but it was the content and schedule of noise exposure that were the dominant influences. From the perspective of the maximal adaptability theory, noise content represents a form of the information structure dimension (with speech providing more information than nonspeech noise), whereas schedule is a form of information rate. The pattern of effect sizes for Noise Schedule × Noise Type analyses followed the form predicted by the theory. For instance, intermittent nonspeech noise had a negligible effect ($g = -0.07$) on performance (and this combination falls within the region of relatively stable performance; see Figure 4). In contrast, intermittent speech-based noise had a large effect ($g = -0.83$; see Table 5 and Figure 7).

One implication of this interpretation is that, for a given task, if the parameters of both noise and task could be manipulated quantitatively, one could derive a function that predicts the level of each parameter at which the thresholds occur (see Figure 5). Most experiments investigating noise have adopted the traditional categorical approach of experimental psychology. We suggest that in the future, this approach be at least augmented by a mathematical modeling approach by which the stress-adaptation functions can be estimated a priori for a set of parameters. This approach would permit a more fine-grained analysis of noise effects on cognitive tasks than was possible to achieve in the present meta-analysis. Future work to establish such an analysis of effects would serve to improve the precision of theoretical models and to potentially increase the effectiveness of mitigation efforts in operational settings.

Importance of Change

As indicated previously, the current results with respect to the schedule and intensity of noise exposure support Loeb's (1986) contention that change in the pattern of noise constitutes a crucial variable that moderates the relationship between noise and performance. Indeed, recent evidence indicates that unpredictable change in environmental input (including the task itself) may be one of the most significant sources of stress. For instance, Helton et al. (2008) reported that changes in demand level of a vigilance task imposed greater levels of distress relative to conditions in which the demand remained constant.

The importance of change in determining noise effects was also noted in Jones's (1993; Macken et al., 2009) object-oriented episodic record model. Recall that according to this model, events, or *objects* (both speech and nonspeech), are segmented and organized into streams of sequential events that are linked. Noise impairs performance by disrupting the links between objects in working memory. However, this model limits its scope to serial recall tasks, and it explicitly indicates that disruption occurs only on tasks that impose such working memory demands.

A broader approach to explaining noise effects in terms of change was reported by De Coensel et al. (2009), who proposed a model of sound perception based on *notice events*. A notice event is defined as the conscious awareness of an epoch of sound. Essentially, noise has an effect only if it is noticed, where the latter function is determined by the level of attention, sound intensity, and strength of habituation to the stimulus. De Coensel et al. presented a computational model of the effects of noise on annoyance. Unfortunately, annoyance represents a subjective state that may or may not generalize to more objective performance effects, which are the present primary concern. However, these authors did suggest the possibility of application of their model to performance effects, and they noted the importance of linking the parameters of their model to patterns of performance outcomes observed in empirical research. The current meta-analysis serves to provide a definitive summary of such patterns to test their model. The notice event model is consistent with main effects for noise type and schedule observed in this study (i.e., noise is presumably more noticeable if it is composed of intermittent speech), but the capacity of this model to explain the task differences and interactions remains to be determined. Nevertheless, the current results are consistent with the argument that variation in acoustic noise can impair performance, possibly by diverting attention.

Relevance of Noise Research in the 21st Century

It is interesting that now, a quarter century after Loeb (1986) identified the need for more research on speech noise and the interaction of noise type with other variables, the current review indicates that in the intervening interval, there have been only relatively limited efforts to resolve such issues. We are, of course, aware of the waxing and waning of interest in many topics of psychological research. With respect to noise, it may be that as Western economies have moved from an emphasis on manufacturing to more service and information-processing work, the issue of industrial noise may seem to be less crucial than it once appeared. Indeed, our meta-analytic review revealed that the number of studies of noise effects on performance has, in general, declined markedly across the immediately preceding decades. However, noise persists as a source of stress in both civilian (e.g., office noise) and military (e.g., combat operations; Humes, Joellenbeck, & Durch, 2006) contexts. It is therefore our contention that noise should continue to be investigated because of its presence in numerous occupational and residential environments. Indeed, the present results point to the importance of speech-based noise interference, which the ubiquitous modern cell phone serves to induce in many modern settings. Further, modern personal technological devices, such as iPods, generate a strong potential for deleterious effects of noise on performance, not to mention health and general well-being. The results of the present meta-analysis indicate that the regulation of noise in these environments should not be based on the assumption of equivalency across all circumstances. When evaluating the performance effects of noise, researchers and practitioners should consider not only the intensity and duration of noise but also the content and schedule of the exposure and the type of task being performed.

Boundaries of Meta-Analysis: A Threshold for Effect Sizes

During the course of our work, it has become clear that there are some interesting boundaries associated with the meta-analytic technique itself. On the most simplistic level, it is clear that any meta-analytic procedure has to use information for at least two separate, independent effect sizes. However, in reality, it may well be that there is a minimum effective number to provide some degree of insight into collective trends. In keeping with previous magic numbers in psychology, we suggest that this might be (arbitrarily) set at seven separate effect sizes. In our present work, we have seen basic, interactive effects at the second-order level that generally exceed this (see Tables 4–8), and we even have third-order interactions in which we have a collection of effect sizes that exceeds this number. In the present case, these results are presented externally from the printed material (see the supplemental materials). All of these issues pertain to the minimum level for sufficient information aggregation. However, there is perhaps an even more interesting threshold that lies at the upper boundary of effect sizes in the analysis of a single moderator. In this simple case, one reaches a certain value of overall effect (e.g., a value for Hedges's g) in which to significantly alter that value—say, to take the overall effect from a weak or small level to a medium level—one would have to introduce a single effect value that would be naturally rejected by the rules of selection. In a previous meta-analysis, for example (see Hancock, Ross, & Szalma, 2007), we had to reject one single effect that was calculated at a value of 17 because it fell so far from the mean level established by all other studies.

We posit, therefore, that it may be possible to derive a description of this threshold that is contingent on the values chosen as criteria for describing the magnitude of a mean effect size (e.g., small, medium, large). We have not provided such a formal calculation, but we believe in the present meta-analysis that we have reached this value for certain of the main effects reported. Of interest, this could serve as a *stopping rule* for meta-analytic procedures. It also suggests that a repository of established knowledge can be sequentially achieved by identifying which factors are likely to induce the greatest shift in effect size magnitude. The empirical studies that would then be needed to create such a shift in understanding of a phenomenon would generate interesting paradigmatic questions.

Summary

In summary, existing theoretical accounts of noise effects based on arousal or masking effects were largely not supported by the present meta-analytic review. A better explanation derives from the maximal adaptability theory (Hancock & Warm, 1989) and a resource-based model of compensatory effort (Hockey, 1997) that describes the relation between noise and task characteristics and the adaptive response of the individual. From this perspective, intermittent speech noise of relatively short duration is most disruptive because it consumes information-processing resources that the individual cannot effectively replenish through compensatory effort because of the limited exposure to the stressor. In contrast, for conditions of continuous noise of longer duration, individuals can develop more effective coping strategies. An implication is that with repeated training sessions, one may be able to develop effective coping for intermittent short-duration speech noise. Still, this is an empirical question. We are also unaware of studies using multiple sessions or longitudinal approaches for the mitigation of performance degradation under conditions of noise stress. These could be a fruitful avenue for future empirical research and one that more closely approximates multiple stress exposures representative of operational environments (e.g., see Hancock & Pierce, 1985). Next, our conclusions are summarized.

1. Arousal and masking may play a role under some conditions (e.g., tasks requiring communication), but they are unlikely to be the central explanatory concepts for noise effects as proposed by Poulton (1979). However, future research should more thoroughly examine the differential effects of noise on energetic versus tense arousal.

2. A resource-based approach to stress, performance, and adaptation can explain most of the effects observed. The overall pattern of findings is most consistent with the resource-based theory of Hancock and Warm (1989) compared with other competing theoretical constructs.

3. Consistent with the observations of Broadbent (1978), Poulton (1979), and Loeb (1986), intermittent noise is more disruptive than a continuous schedule.

4. These effects occur more strongly with speech noise and for resource-demanding cognitive tasks.

5. Poulton's (1981a) argument that accuracy should be more susceptible than speed to noise effects has been confirmed.

6. Loeb's (1986) argument that the intensity itself may not be of central importance was supported by the evidence presented here.

7. The divergence in intensity effects as a function of noise manipulations suggests that future researchers should consider either the inclusion of two control groups (i.e., quiet condition as well as lower dB noise) and that the intensity of the quiet condition be measured and specified in all publications of noise effects.

8. Future empirical research should examine potential differences in structural versus strategic effects of noise exposure.

References

*References marked with an asterisk indicate studies included in the meta-analysis.

*Allen, R. W., Magdaleno, R. E., & Jex, H. R. (1975). *Effects of wideband auditory noise on manual control performance and dynamic response* (Technical Report AMRL-TR-75-65). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

*Amir, N., McNally, R. J., & Wiegartz, P. S. (1996). Implicit memory bias for threat in posttraumatic stress disorder. *Cognitive Therapy and Research, 20,* 625–635. doi:10.1007/BF02227965

*Armstrong, G. B., & Greenberg, B. S. (1990). Background television as an inhibitor of cognitive processing. *Human Communication Research, 16,* 355–386. doi:10.1111/j.1468-2958.1990.tb00215.x

Baddeley, A., & Hitch, G. J. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 47–90). New York, NY: Academic Press.

*Baddeley, A., & Salamé, P. (1986). The unattended speech effect: Perception or memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 525–529. doi:10.1037/0278-7393.12.4.525

*Ballard, J. C. (1993). *Effects of task demand, noise, and pretest anxiety on vigilance performance and changes in anxiety state* (Unpublished doctoral dissertation). Emory University, Atlanta, GA.

*Banbury, S., & Berry, D. C. (1997). Habituation and dishabituation to speech and office noise. *Journal of Experimental Psychology: Applied, 3,* 181–195. doi:10.1037/1076-898X.3.3.181

*Banbury, S., & Berry, D. C. (1998). Disruption of office-related tasks by speech and office noise. *British Journal of Psychology, 89,* 499–517. doi:10.1111/j.2044-8295.1998.tb02699.x

*Barker, J., & Cooke, M. (2007). Modeling speaker intelligibility in noise. *Speech Communication, 49,* 402–417. doi:10.1016/j.specom.2006.11.003

*Beaman, C. P. (2004). The irrelevant sound phenomenon revisited: What role for working memory capacity? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1106–1118. doi:10.1037/0278-7393.30.5.1106

*Beaman, C. P., & Jones, D. M. (1997). Role of serial order in the irrelevant speech effect: Tests of the changing-state hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 459–471. doi:10.1037/0278-7393.23.2.459

*Beaman, C. P., & Jones, D. M. (1998). Irrelevant sound disrupts order information in free recall as in serial recall. *Quarterly Journal of Experimental Psychology: A. Human Experimental Psychology, 51,* 615–636. doi:10.1080/027249898391558

*Becker, A. B., Warm, J. S., Dember, W. N., & Hancock, P. A. (1995). Effects of jet engine, noise and performance feedback on perceived workload in a monitoring task. *International Journal of Aviation Psychology, 5,* 49–62. doi:10.1207/s15327108ijap0501_4

Becker, B. J. (1988). Synthesizing standardized mean-change measures. *British Journal of Mathematical and Statistical Psychology, 41,* 257–278.

*Bell, P. A. (1978). Effects of noise and heat stress on primary and subsidiary task performance. *Human Factors, 20,* 749–752.

*Bell, P. A. (1984). Noise and context-dependent memory. *Bulletin of the Psychonomic Society, 22,* 99–100.

*Bienstock, B. (1990). *The effects of caffeine and noise on visual two-pulse discrimination and vigilance* (Unpublished doctoral dissertation). City University of New York, New York, NY.

*Boggs, D. H., & Simon, J. R. (1968). Differential effects of noise on tasks of varying complexity. *Journal of Applied Psychology, 52,* 148–153. doi:10.1037/h0025496

*Breen-Lewis, K., & Wilding, J. (1984). Noise, time of day and test expectations in recall and recognition. *British Journal of Psychology, 75,* 51–63. doi:10.1111/j.2044-8295.1984.tb02789.x

*Bridges, A. M., & Jones, D. M. (1996). Word dose in the disruption of serial recall by irrelevant speech: Phonological confusions or changing state? *Quarterly Journal of Experimental Psychology: A. Human Experimental Psychology, 49,* 919–939. doi:10.1080/027249896392360

Broadbent, D. E. (1958). *Perception and communication.* New York, NY: Pergamon Press.

Broadbent, D. E. (1971). *Decision and stress.* London, England: Academic Press.

Broadbent, D. E. (1976). Noise and the details of experiments: A reply to Poulton. *Applied Ergonomics, 7,* 231–235. doi:10.1016/0003-6870(76)90107-1

Broadbent, D. E. (1977). Precautions in experiments on noise. *British Journal of Psychology, 68,* 427–429. doi:10.1111/j.2044-8295.1977.tb01608.x

Broadbent, D. E. (1978). The current state of noise research: Reply to Poulton. *Psychological Bulletin, 85,* 1052–1067. doi:10.1037/0033-2909.85.5.1052

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10,* 12–21. doi:10.1080/17470215808416249

Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C. (2008). A meta-analysis of the effects of cell phones on driver performance. *Accident Analysis and Prevention, 40,* 1282–1293. doi:10.1016/j.aap.2008.01.009

*Campbell, T., Beaman, C. P., & Berry, D. C. (2002a). Auditory memory and the irrelevant sound effect: Further evidence for changing-state disruption. *Memory, 10,* 199–214. doi:10.1080/09658210143000335

*Campbell, T., Beaman, C. P., & Berry, D. C. (2002b). Changing-state disruption of lip-reading by irrelevant sound in perceptual and memory tasks. *European Journal of Cognitive Psychology, 14,* 461–474. doi:10.1080/09541440143000168

*Carter, N. L., & Beh, H. C. (1989). The effect of intermittent noise on cardiovascular functioning during vigilance task performance. *Psychophysiology, 26,* 548–559. doi:10.1111/j.1469-8986.1989.tb00708.x

Casali, J. G., & Robinson, G. S. (1999). Noise in industry: Auditory effects, measurement, regulations, and management. In W. Karwowski & W. Marras (Ed.), *The occupational ergonomics handbook* (pp. 1661–1692). Boca Raton, FL: CRC Press.

*Cassel, E. E., & Dallenbach, K. M. (1918). The effect of auditory distraction upon the sensory reaction. *American Journal of Psychology, 29,* 129–143. doi:10.2307/1413558

*Cassidy, G., & MacDonald, R. A. R. (2007). The effect of background music and background noise on the task performance of introverts and extraverts. *Psychology of Music, 35,* 517–537. doi:10.1177/0305735607076444

*Chatterjee, A., & Krishnamurty, V. (1972). Differential effect of noise as an environmental stress. *Behaviorometric, 2,* 1–8.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *Journal of the Acoustical Society of America, 25,* 975–979. doi:10.1121/1.1907229

Cheung, S. F., & Chan, D. K. S. (2004). Dependent effect sizes in meta-analysis: Incorporating the degree of interdependence. *Journal of Applied Psychology, 89,* 780–791. doi: 10.1037/0021-9010.89.5.780

Clark, C. R. (1984). The effects of noise on health. In D. M. Jones & A. J. Chapman (Eds.), *Noise and society* (pp. 111–124). New York, NY: Wiley.

Cohen, S., & Spacapan, S. (1978). The aftereffects of stress: An attentional interpretation. *Environmental Psychology and Nonverbal Behavior, 3,* 43–57. doi:10.1007/BF01114531

*Colle, H. A. (1980). Auditory encoding in visual short-term recall: Effects of noise intensity and spatial location. *Journal of Verbal Learning and Verbal Behavior, 19,* 722–735. doi:10.1016/S0022-5371(80)90403-X

*Colle, H. A., & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior, 15,* 17–31. doi:10.1016/S0022-5371(76)90003-7

*Colquhoun, W. P., & Edwards, R. S. (1975). Interaction of noise with alcohol on a task of sustained attention. *Ergonomics, 18,* 81–87. doi:10.1080/00140137508931441

Conway, G. E., Szalma, J. L., & Hancock, P. A. (2007). A quantitative meta-analytic examination of whole-body vibration effects on human performance. *Ergonomics, 50,* 228–245. doi:10.1080/00140130600980888

Cooper, H., & Hedges, L. V. (Eds.). (1994). *The handbook of research synthesis.* New York, NY: Russell Sage Foundation.

*Daee, S., & Wilding, J. M. (1977). Effects of high intensity white noise on short-term memory for position in a list and sequence. *British Journal of Psychology, 68,* 335–349. doi:10.1111/j.2044-8295.1977.tb01598.x

*Davenport, W. G. (1972). Vigilance and arousal: Effects of different types of background stimulation. *Journal of Psychology: Interdisciplinary and Applied, 82,* 339–346. doi:10.1080/00223980.1972.9923824

*Davies, A. D., & Davies, D. R. (1975). The effects of noise and time of day upon age differences in performance at two checking tasks. *Ergonomics, 18,* 321–336. doi:10.1080/00140137508931465

*Davies, D. R., & Jones, D. M. (1975). The effects of noise and incentives upon attention in short-term memory. *British Journal of Psychology, 66,* 61–68. doi:10.1111/j.2044-8295.1975.tb01440.x

*Dean, R. D., & McGlothen, C. L. (1965). Effects of combined heat and noise on human performance, physiology, and subjective estimates of comfort and performance. In *Proceedings of the Institute of Environmental Sciences annual technical meeting* (pp. 55–64).

De Coensel, B., Botteldooren, D., De Muer, T., Berglund, B., Nilsson, M. E., & Lercher, P. (2009). A model for the perception of environmental sound based on notice-events. *Journal of the Acoustical Society of America, 126,* 656–665. doi:10.1121/1.3158601

*Dwivedi, C. B., Singh, N. B., & Singh, I. L. (1982). Differential role of meaningfulness, white noise and intentionality of recall. *Psychological Studies, 27,* 8–11.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66,* 183–201.

Engel, Z., Augustynska, D., Koton, J., & Kacmarska, A. (2006). Noise: Definitions. In W. Karwowski (Ed.), *International encyclopedia of ergonomics and human factors* (Vol. 2, pp. 1826–1841). Boca Raton, FL: CRC Press/Taylor & Francis. doi:10.1201/9780849375477.ch361

*Enmarker, I., Boman, E., & Hygge, S. (2006). Structural equation models of memory performance across noise conditions and age groups. *Scan-*

dinavian Journal of Psychology, 47, 449–460. doi:10.1111/j.1467-9450.2006.00556.x

*Evans, G. W., Allen, K. M., Tafalla, R., & O'Meara, T. (1996). Multiple stressors: Performance, psychophysiological and affective responses. *Journal of Environmental Psychology, 16,* 147–154. doi:10.1006/jevp.1996.0012

*Eysenck, M. W. (1975). Effects of noise, activation level, and response dominance on retrieval from semantic memory. *Journal of Experimental Psychology: Human Learning and Memory, 1,* 143–148. doi:10.1037/0278-7393.1.2.143

*Fisher, S. (1972). A "distraction effect" of noise bursts. *Perception, 1,* 223–236. doi:10.1068/p010223

*Fisher, S. (1983a). Memory and search in loud noise. *Canadian Journal of Psychology/Revue Canadienne de Psychologie, 37,* 439–449. doi:10.1037/h0080737

*Fisher, S. (1983b). "Pessimistic noise effects": The perception of reaction times in noise. *Canadian Journal of Psychology/Revue Canadienne de Psychologie, 37,* 258–271. doi:10.1037/h0080717

Fletcher, H., & Munson, W. A. (1933). Loudness, its definition, measurement, and calculation. *Journal of the Acoustical Society of America, 5,* 82–108. doi:10.1121/1.1915637

*Fowler, C. J., & Wilding, J. (1979). Differential effects of noise and incentives on learning. *British Journal of Psychology, 70,* 149–153. doi:10.1111/j.2044-8295.1979.tb02153.x

*Frith, C. D. (1967). The interaction of noise and personality with critical flicker fusion performance. *British Journal of Psychology, 58,* 127–131. doi:10.1111/j.2044-8295.1967.tb01065.x

*Gisselbrecht-Simon, D. (1988). Concreteness encoding through a dual task procedure: Arguments in favour of an automatic process. *Acta Psychologica, 67,* 145–155. doi:10.1016/0001-6918(88)90010-8

*Gulian, E., & Thomas, J. R. (1986). The effects of noise, cognitive set and gender on mental arithmetic performance. *British Journal of Psychology, 77,* 503–511. doi:10.1111/j.2044-8295.1986.tb02214.x

*Hamilton, P., & Copeman, A. (1970). The effect of alcohol and noise on components of a tracking and monitoring task. *British Journal of Psychology, 61,* 149–156. doi:10.1111/j.2044-8295.1970.tb01232.x

Hancock, P. A., & Desmond, P. A. (Eds.). (2001). *Stress, workload, and fatigue.* Mahwah, NJ: Erlbaum.

Hancock, P. A., & Ganey, H. C. N. (2003). From the inverted-U to the extended-U: The evolution of a law of psychology. *Journal of Human Performance in Extreme Environments, 7,* 5–14.

Hancock, P. A., Mouloua, M., & Senders, J. W. (2008). On the philosophical foundations of driving distraction and the distracted driver. In K. L. Young, J. D. Lee, & M. A. Regan (Eds.), *Driver distraction theory: Effects and mitigation* (pp. 11–30). Boca Raton, FL: CRC Press. doi:10.1201/9781420007497.pt2

Hancock, P. A., & Pierce, J. O. (1985). Combined effects of heat and noise on human performance: A review. *American Industrial Hygiene Association Journal, 46,* 555–566. doi:10.1080/15298668591395346

Hancock, P. A., Ross, J. M., & Szalma, J. L. (2007). A meta-analysis of performance response under thermal stressors. *Human Factors, 49,* 851–877. doi:10.1518/001872007X230226

Hancock, P. A., & Szalma, J. L. (2008). Stress and performance. In P. A. Hancock & J. L. Szalma (Eds.), *Performance under stress* (pp. 1–18). Aldershot, United Kingdom: Ashgate.

Hancock, P. A., & Vastmizidis, I. (1998). Human occupational and performance limits under stress: The thermal environment as a prototypical example. *Ergonomics, 41,* 1169–1191. doi: 10.1080/001401398186469

Hancock, P. A., & Warm, J. S. (1989). A dynamic model of stress and sustained attention. *Human Factors, 31,* 519–537.

*Hanley, J. R. (1997). Does articulatory suppression remove the irrelevant speech effect? *Memory, 5,* 423–431. doi:10.1080/741941394

*Hanley, J. R., & Broadbent, C. (1987). The effect of unattended speech on serial recall following auditory presentation. *British Journal of Psychology, 78,* 287–297. doi:10.1111/j.2044-8295.1987.tb02247.x

*Hartley, L. R. (1974). Performance during continuous and intermittent noise and wearing ear protection. *Journal of Experimental Psychology, 102,* 512–516. doi:10.1037/h0035853

*Hartley, L. R. (1981a). Noise, attentional selectivity, serial reactions and the need for experimental power. *British Journal of Psychology, 72,* 101–107. doi:10.1111/j.2044-8295.1981.tb02167.x

Hartley, L. R. (1981b). Noise does not impair by masking: A reply to Poulton's "Composite Model for Human Performance in Continuous Noise." *Psychological Review, 88,* 86–89. doi:10.1037/0033-295X.88.1.86

*Hartley, L. R., & Adams, R. G. (1974). Effect of noise on the Stroop test. *Journal of Experimental Psychology, 102,* 62–66. doi:10.1037/h0035695

*Hartley, L. R., & Carpenter, A. (1974). Comparison of performance with headphone and free-field noise. *Journal of Experimental Psychology, 103,* 377–380. doi:10.1037/h0036796

*Hartley, L. R., Dunne, M., Schwartz, S., & Brown, J. (1986). Effect of noise on cognitive strategies in a sentence verification task. *Ergonomics, 29,* 607–617. doi:10.1080/00140138608968295

Hebb, D. O. (1955). Drives and the C. N. S. (conceptual nervous system). *Psychological Review, 62,* 243–254. doi:10.1037/h0041823

Hedges, L. V., & Olkin, I. (1985). *Statistical methods for meta-analysis.* New York, NY: Academic Press.

Hedges, L. V., Shymansky, J. A., & Woodworth, G. (1989). *A practical guide to modern methods of meta-analysis.* Washington, DC: National Science Teachers Association.

Hedges, L. V., & Vevea, J. L. (1998). Fixed- and random-effects models in meta-analysis. *Psychological Methods, 3,* 486–504. doi:10.1037/1082-989X.3.4.486

*Heinrich, A., Schneider, B. A., & Craik, F. I. M. (2008). Investigating the influence of continuous babble on auditory short-term memory performance. *Quarterly Journal of Experimental Psychology, 61,* 735–751. doi:10.1080/17470210701402372

*Helton, W. S., Matthews, G., & Warm, J. S. (2009). Stress state mediation between environmental variables and performance: The case of noise and vigilance. *Acta Psychologica, 130,* 204–213. doi:10.1016/j.actpsy.2008.12.006

Helton, W. S., Shaw, T., Warm, J. S., Matthews, G., & Hancock, P. (2008). Effects of warned and unwarned demand transitions on vigilance performance and stress. *Anxiety, Stress & Coping, 21,* 173–184. doi:10.1080/10615800801911305

*Helton, W. S., Warm, J. S., Matthews, G., Corcoran, K. J., & Dember, W. N. (2002). Further tests of an abbreviated vigilance task: Effects of signal salience and jet aircraft noise on performance and stress. *Proceedings of the Human Factors and Ergonomics Society, 46,* 1546–1550.

*Henson, R., Hartley, T., Burgess, N., Hitch, G., & Flude, B. (2003). Selective interference with verbal short-term memory for serial order information: A new paradigm and tests of a timing-signal hypothesis. *Quarterly Journal of Experimental Psychology: A. Human Experimental Psychology, 56,* 1307–1334. doi:10.1080/02724980244000747

*Hockey, G. R. J. (1973). *The effects of noise and of loss of sleep upon the observation of 3 sources of signals with unequal probabilities* (Technical Report ADA032156). London, England: Royal Navy Personnel Research Committee.

Hockey, G. R. J. (1986). Changes in operator efficiency as a function of environmental stress, fatigue, and circadian rhythms. In L. Kaufman, K. R. Boff, & J. P. Thomas (Eds.), *Handbook of human perception and performance: Vol. 2. Cognitive processes and performance* (pp. 1–49). New York, NY: Wiley.

Hockey, G. R. J. (1997). Compensatory control in the regulation of human performance under stress and high workload: A cognitive–energetical framework. *Biological Psychology, 45,* 73–93. doi:10.1016/S0301-0511(96)05223-4

Hockey, G. R. J., & Hamilton, P. (1983). The cognitive patterning of stress states. In G. R. J. Hockey (Ed.), *Stress and human performance* (pp. 331–362). Chichester, England: Wiley.

Hockey, R. (1984). Varieties of attentional state: The effects of environment. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 449–483). New York, NY: Academic Press.

Holding, D. H., & Baker, M. A. (1987). Toward meaningful noise research. *Journal of General Psychology, 114,* 395–410.

Huffcutt, A. I., & Arthur, W. (1995). Development of a new outlier statistic or meta-analytic data. *Journal of Applied Psychology, 80,* 327–334. doi:10.1037/0021-9010.80.2.327

Humes, L. E., Joellenbeck, L. M., & Durch, J. S. (Eds.). (2006). *Noise and military service.* Washington, DC: National Academies Press.

Hunter, J. E., & Schmidt, F. L. (2004). *Methods of meta-analysis: Correcting for error and bias in research findings.* Thousand Oaks, CA: Sage.

*Hygge, S., Boman, E., & Enmarker, I. (2003). The effects of road traffic noise and meaningful irrelevant speech on different memory systems. *Scandinavian Journal of Psychology, 44,* 13–21. doi:10.1111/1467-9450.00316

*Hygge, S., & Knez, I. (2001). Effects of noise, heat and indoor lighting on cognitive performance and self-reported affect. *Journal of Environmental Psychology, 21,* 291–299. doi:10.1006/jevp.2001.0222

*Jerison, H. J. (1957). Performance on a simple vigilance task in noise and quiet. *Journal of the Acoustical Society of America, 29,* 1163–1165. doi:10.1121/1.1908729

*Jerison, H. J. (1959). Effects of noise on human performance. *Journal of Applied Psychology, 43,* 96–101. doi:10.1037/h0042914

*Jerison, H. J., & Smith, A. K. (1955). *Effects of acoustic noise on time judgment* (Technical Report 7193). Wright-Patterson Air Force Base, OH: Aero Medical Laboratory.

*Jerison, H. J., & Wing, S. (1957). *Effects of noise and fatigue on a complex vigilance task* (Technical Report 57-14). Wright-Patterson Air Force Base, OH: Wright Air Development Center.

Jones, D. M. (1983). Noise. In G. R. J. Hockey (Ed.), *Stress and fatigue in human performance* (pp. 61–95). Chichester, England: Wiley.

Jones, D. M. (1993). Objects, streams, and threads of auditory attention. In A. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness, and control* (pp. 87–104). Oxford, England: Oxford University Press.

*Jones, D. M., Alford, D., Bridges, A., Tremblay, S. B., & Macken, B. (1999). Organizational factors in selective attention: The interplay of acoustic distinctiveness and auditory streaming in the irrelevant sound effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 464–473. doi:10.1037/0278-7393.25.2.464

*Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 369–381. doi:10.1037/0278-7393.19.2.369

*Jones, D. M., & Macken, W. J. (1995a). Auditory babble and cognitive efficiency: Role of number of voices and their location. *Journal of Experimental Psychology: Applied, 1,* 216–226. doi:10.1037/1076-898X.1.3.216

*Jones, D. M., & Macken, W. J. (1995b). Phonological similarity in the irrelevant speech effect: Within- or between-stream similarity? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 103–115. doi:10.1037/0278-7393.21.1.103

*Jones, D. M., Macken, W. J., & Mosdell, N. A. (1997). The role of habituation in the disruption of recall performance by irrelevant sound. *British Journal of Psychology, 88,* 549–564. doi:10.1111/j.2044-8295.1997.tb02657.x

Jones, D. M., & Morris, N. (1992). Irrelevant speech and cognition. In A. P. Smith & D. M. Jones (Eds.), *Handbook of human performance: Vol. 1. Physical environment* (pp. 29–53). London, England: Academic Press.

*Jones, D. M., Smith, A. P., & Broadbent, D. E. (1979). Effects of moderate intensity noise on the Bakan vigilance task. *Journal of Applied Psychology, 64,* 627–634. doi:10.1037/0021-9010.64.6.627

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

*Kirk, R. E., & Hecht, E. (1963). Maintenance of vigilance by programmed noise. *Perceptual and Motor Skills, 16,* 553–560.

*Kjellberg, A., Ljung, R., & Hallman, D. (2008). Recall of words heard in noise. *Applied Cognitive Psychology, 22,* 1088–1098. doi:10.1002/acp.1422

*Knez, I., & Hygge, S. (2002). Irrelevant speech and indoor lighting: Effects of cognitive performance and self-reported affect. *Applied Cognitive Psychology, 16,* 709–718. doi:10.1002/acp.829

*Lahtela, K., Niemi, P., Kuusela, V., & Hypen, K. (1986). Noise and visual choice-reaction time: A large-scale population survey. *Scandinavian Journal of Psychology, 27,* 52–57. doi:10.1111/j.1467-9450.1986.tb01186.x

*Larsen, J. D., & Baddeley, A. (2003). Disruption of verbal STM by irrelevant speech, articulatory suppression, and manual tapping: Do they have a common source? *Quarterly Journal of Experimental Psychology: A. Human Experimental Psychology, 56,* 1249–1268. doi:10.1080/02724980244000765

*Larsen, J. D., Baddeley, A., & Andrade, J. (2000). Phonological similarity and the irrelevant speech effect: Implications for models of short-term verbal memory. *Memory, 8,* 145–157. doi:10.1080/096582100387579

Lazarus, R. S. (1999). *Stress and emotion: A new synthesis.* New York, NY: Springer.

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping.* New York, NY: Springer-Verlag.

*LeCompte, D. C. (1994). Extending the irrelevant speech effect beyond serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1396–1408. doi:10.1037/0278-7393.20.6.1396

*LeCompte, D. C. (1995). An irrelevant speech effect with repeated and continuous background speech. *Psychonomic Bulletin & Review, 2,* 391–397. doi:10.3758/BF03210978

*LeCompte, D. C. (1996). Irrelevant speech, serial rehearsal, and temporal distinctiveness: A new approach to the irrelevant speech effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1154–1165. doi:10.1037/0278-7393.22.5.1154

*LeCompte, D. C., Neely, C. B., & Wilson, J. R. (1997). Irrelevant speech and irrelevant tones: The relative importance of speech to the irrelevant speech effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 472–483. doi:10.1037/0278-7393.23.2.472

*LeCompte, D. C., & Shaibe, D. M. (1997). On the irrelevance of phonological similarity to the irrelevant speech effect. *Quarterly Journal of Experimental Psychology: A. Human Experimental Psychology, 50,* 100–118. doi:10.1080/027249897392242

Lesch, M. F., & Hancock, P. A. (2004). Driving performance during concurrent cell-phone use: Are drivers aware of their performance decrements? *Accident Analysis and Prevention, 36,* 471–480. doi:10.1016/S0001-4575(03)00042-3

*Levy-Leboyer, C. (1989). Noise effects on two industrial tasks. *Work & Stress, 3,* 315–322. doi:10.1080/02678378908256949

Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis.* Thousand Oaks, CA: Sage.

*Ljungberg, J. K., & Neely, G. (2007). Stress, subjective experience and cognitive performance during exposure to noise and vibration. *Journal of Environmental Psychology, 27,* 44–54. doi:10.1016/j.jenvp.2006.12.003

Loeb, M. (1981). The present state of research on the effects of noise: Are we asking the right questions? *Journal of Auditory Research, 21,* 93–104.

Loeb, M. (1986). *Noise and human efficiency.* Chichester, England: Wiley.

*Loeb, M., Holding, D. H., & Baker, M. A. (1982). Noise stress and circadian arousal in self-paced computation. *Motivation and Emotion, 6,* 43–48. doi:10.1007/BF00992136

*Loeb, M., & Jones, P. D. (1978). Noise exposure, monitoring and tracking performance as a function of signal bias and task priority. *Ergonomics, 21,* 265–272. doi:10.1080/00140137808931723

*Loewen, L. J., & Suedfeld, P. (1992). Cognitive and arousal effects of masking office noise. *Environment and Behavior, 24,* 381–395. doi:10.1177/0013916592243006

Lundberg, U., & Frankenhaeuser, M. (1978). Psychophysiological reactions to noise as modified by personal control over noise intensity. *Biological Psychology, 6,* 51–59. doi:10.1016/0301-0511(78)90006-6

*Macken, W. J., Mosdell, N., & Jones, D. M. (1999). Explaining the irrelevant-sound effect: Temporal distinctiveness or changing state? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 810–814. doi:10.1037/0278-7393.25.3.810

*Macken, W. J., Phelps, F. G., & Jones, D. M. (2009). What causes auditory distraction? *Psychonomic Bulletin & Review, 16,* 139–144. doi:10.3758/PBR.16.1.139

*Macken, W. J., Tremblay, S. B., Houghton, R. J., Nicholls, A. P., & Jones, D. M. (2003). Does auditory streaming require attention? Evidence from attentional selectivity in short-term memory. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 43–51. doi:10.1037/0096-1523.29.1.43

*Marsh, J. E., Hughes, R. W., & Jones, D. M. (2008). Auditory distraction in semantic memory: A process-based approach. *Journal of Memory and Language, 58,* 682–700. doi:10.1016/j.jml.2007.05.002

*Marsh, J. E., Hughes, R. W., & Jones, D. M. (2009). Interference by process, not content, determines semantic auditory distraction. *Cognition, 110,* 23–38. doi:10.1016/j.cognition.2008.08.003

*Marsh, J. E., Vachon, F. O., & Jones, D. M. (2008). When does between-sequence phonological similarity promote irrelevant sound disruption? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 243–248. doi:10.1037/0278-7393.34.1.243

*Martin, R. C., Wogalter, M. S., & Forlano, J. G. (1988). Reading comprehension in the presence of unattended speech and music. *Journal of Memory and Language, 27,* 382–398. doi:10.1016/0749-596X(88)90063-0

Martinussen, M., & Bjornstad, J. F. (1999). Meta-analysis calculations based on independent and nonindependent cases. *Educational and Psychological Measurement, 59,* 928–950. doi:10.1177/00131649921970260

Matthews, G. (2001). Levels of transaction: A cognitive science framework for operator stress. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload, and fatigue* (pp. 5–33). Mahwah, NJ: Erlbaum.

Matthews, G., Campbell, S. E., Falconer, S., Joyner, L. A., Huggins, J., Gilliland, K., . . . Warm, J. S. (2002). Fundamental dimensions of subjective state in performance settings: Task engagement, distress, and worry. *Emotion, 2,* 315–340. doi:10.1037/1528-3542.2.4.315

*McBain, W. N. (1961). Noise, the "arousal hypothesis," and monotonous work. *Journal of Applied Psychology, 45,* 309–317. doi:10.1037/h0049015

McEwen, B. S. (2002). *The end of stress as we know it*. Washington, DC: Henry Press.

*Mech, E. V. (1953). Factors influencing routine performance under noise: I. The influence of "set." *Journal of Psychology: Interdisciplinary and Applied, 35,* 283–298. doi:10.1080/00223980.1953.9712863

*Meijer, W. A., de Groot, R. H. M., Van Boxtel, M. P. J., Van Gerven, P. W. M., & Jolles, J. (2006). Verbal learning and aging: Combined effects of irrelevant speech, interstimulus interval, and education. *Journals of Gerontology: Series B. Psychological Sciences and Social Sciences, 61,* P285–P294.

*Michalewski, H. J., Starr, A., Zeng, F.-G., & Dimitrijevic, A. (2009). N100 cortical potentials accompanying disrupted auditory nerve activity in auditory neuropathy (AN): Effects of signal intensity and continuous noise. *Clinical Neurophysiology, 120,* 1352–1363. doi:10.1016/j.clinph.2009.05.013

*Miles, C., Auburn, T. C., & Jones, D. M. (1984). Effects of loud noise and signal probability on visual vigilance. *Ergonomics, 27,* 855–862. doi:10.1080/00140138408963559

*Miles, C., Jones, D. M., & Madden, C. A. (1991). Locus of the irrelevant speech effect in short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 578–584. doi:10.1037/0278-7393.17.3.578

*Millar, K. (1979). Noise and the "rehearsal-masking hypothesis." *British Journal of Psychology, 70,* 565–577. doi:10.1111/j.2044-8295.1979.tb01732.x

Morris, S. B., & DeShon, R. P. (2002). Combining effect size estimates in meta-analysis with repeated measures and independent-groups designs. *Psychological Methods, 7,* 105–125. doi:10.1037/1082-989X.7.1.105

*Neath, I., Surprenant, A. M., & LeCompte, D. C. (1998). Irrelevant speech eliminates the word length effect. *Memory & Cognition, 26,* 343–354. doi:10.3758/BF03201145

*Neely, C. B., & LeCompte, D. C. (1999). The importance of semantic similarity to the irrelevant speech effect. *Memory & Cognition, 27,* 37–44. doi:10.3758/BF03201211

*Norris, D., Baddeley, A. D., & Page, M. P. A. (2004). Retroactive effects of irrelevant speech on serial recall from short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1093–1105. doi:10.1037/0278-7393.30.5.1093

*Nurmi, J. E., & Wright, J. (1983). Interactive effects of noise, neuroticism and state-anxiety in the learning and recall of a textbook passage. *Human Learning, 2,* 119–125.

Occupational Safety and Health Administration. (1983). Occupational noise exposure: Hearing conservation amendment. *Federal Register, 48,* 9738–9783.

Orasanu, J. (1997). Stress and naturalistic decision making: Strengthening the weak links. In E. Salas, R. Flin, M. Strub, & L. Martin (Eds.), *Decision making under stress: Emerging themes and applications* (pp. 43–66). Aldershot, United Kingdom: Ashgate.

*Parmentier, F. B. R., & Jones, D. M. (2000). Functional characteristics of auditory temporal and spatial short-term memory: Evidence from serial order errors. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 222–238. doi:10.1037/0278-7393.26.1.222

Pashler, H. E. (1998). *The psychology of attention.* Cambridge, MA: MIT Press.

Peterson, L. R., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58,* 193–198. doi:10.1037/h0049234

*Pollock, K. G., & Bartlett, F. C. (1932). Psychological experiments on the effects of noise I. *Industrial Health Research Board Reports, 65,* 1–37.

*Pollock, K. G., Bartlett, F. C., Weston, H. C., & Adams, S. (1932). Two studies in the psychological effects of noise. I. Psychological experiments on the effects of noise. II. The effects of noise on the performance of weavers. *Industrial Health Research Board Reports, 65,* 38–62.

Poulton, E. C. (1970). *Environment and human efficiency*. Springfield, IL: Charles C Thomas.

Poulton, E. C. (1976). Arousing environmental stresses can improve performance whatever people say. *Aviation, Space, and Environmental Medicine, 47,* 1193–1204.

Poulton, E. C. (1977). Continuous intense noise masks auditory feedback and inner speech. *Psychological Bulletin, 84,* 977–1001. doi:10.1037/0033-2909.84.5.977

Poulton, E. C. (1978). A new look at the effects of noise: A rejoinder. *Psychological Bulletin, 85,* 1068–1079. doi:10.1037/0033-2909.85.5.1068

Poulton, E. C. (1979). Composite model for human performance in continuous noise. *Psychological Review, 86,* 361–375. doi:10.1037/0033-295X.86.4.361

Poulton, E. C. (1981a). Masking, beneficial arousal and adaptation level: A reply to Hartley. *British Journal of Psychology, 72,* 109–116.

Poulton, E. C. (1981b). Not so! Rejoinder to Hartley on masking by continuous noise. *Psychological Review, 88,* 90–92. doi:10.1037/0033-295X.88.1.90

*Salamé, P., & Baddeley, A. D. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behavior, 21,* 150–164. doi:10.1016/S0022-5371(82)90521-7

*Salamé, P., & Baddeley, A. D. (1986). Phonological factors in STM: Similarity and the unattended speech effect. *Bulletin of the Psychonomic Society, 24,* 263–265.

Salamé, P., & Wittersheim, G. (1978). Selective noise disturbance of the information input in short-term memory. *Quarterly Journal of Experimental Psychology, 30,* 693–704. doi:10.1080/14640747808400694

*Sandrock, S., Schutte, M., & Griefahn, B. (2010). Mental strain and annoyance during cognitive performance in different traffic noise conditions. *Ergonomics, 53,* 962–971. doi:10.1080/00140139.2010.500401

Sarason, B. R., Sarason, I. G., & Pierce, G. R. (1990). *Social support: An interactional view.* New York, NY: Wiley.

*Schlittmeier, S. J., Hellbrück, J., Thaden, R., & Vorländer, M. (2008). The impact of background speech varying in intelligibility: Effects on cognitive performance and perceived disturbance. *Ergonomics, 51,* 719–736. doi:10.1080/00140130701745925

Sikström, S., & Soderlund, G. (2007). Stimulus-dependent dopamine release in attention-deficit/hyperactivity disorder. *Psychological Review, 114,* 1047–1075. doi:10.1037/0033-295X.114.4.1047

*Singer, M., Bronstein, D. M., & Miles, J. M. (1981). Effect of noise on priming in a lexical decision task. *Bulletin of the Psychonomic Society, 18,* 187–190.

*Skowronski, M. D., & Harris, J. G. (2006). Applied principles of clear and Lombard speech for automated intelligibility enhancement in noisy environments. *Speech Communication, 48,* 549–558. doi:10.1016/j.specom.2005.09.003

*Smith, A. P. (1983). The effects of noise and time on task on recall of order information. *British Journal of Psychology, 74,* 83–89. doi:10.1111/j.2044-8295.1983.tb01845.x

*Smith, A. P. (1985a). The effects of different types of noise on semantic processing and syntactic reasoning. *Acta Psychologica, 58,* 263–273. doi:10.1016/0001-6918(85)90025-3

*Smith, A. P. (1985b). The effects of noise on recall of lists of associated words. *Current Psychological Research & Reviews, 4,* 17–21. doi:10.1007/BF02686562

*Smith, A. P. (1985c). The effects of noise on the processing of global shape and local detail. *Psychological Research, 47,* 103–108. doi:10.1007/BF00309124

*Smith, A. P. (1985d). Noise, biased probability and serial reaction. *British Journal of Psychology, 76,* 89–95. doi:10.1111/j.2044-8295.1985.tb01933.x

*Smith, A. P. (1987). Activation states and semantic processing: A comparison of the effects of noise and time of day. *Acta Psychologica, 64,* 271–288. doi:10.1016/0001-6918(87)90012-6

*Smith, A. P. (1988). Acute effects of noise exposure: An experimental investigation of the effects of noise and task parameters on cognitive vigilance tasks. *International Archives of Occupational Environmental Health, 60,* 307–310. doi:10.1007/BF00378479

*Smith, A. P. (1990a). Effects of noise and task parameters on dual cognitive vigilance tasks. In B. Brogan (Ed.), *Visual search* (pp. 339–344). Philadelphia, PA: Taylor & Francis.

*Smith, A. P. (1990b). Noise, task parameters and cognitive vigilance tasks. In E. Lovesey (Ed.), *Contemporary ergonomics: Proceedings of the Ergonomics Society's annual conference* (pp. 98–103). London, England: Taylor & Francis.

*Smith, A. P. (1991). Noise and aspects of attention. *British Journal of Psychology, 82,* 313–324. doi:10.1111/j.2044-8295.1991.tb02402.x

Smith, A. P. (2003). The concept of noise sensitivity: Implications for noise control. *Noise & Health, 5,* 59–61.

*Smith, A. P., & Broadbent, D. E. (1981). Noise and levels of processing. *Acta Psychologica, 47,* 129–142. doi:10.1016/0001-6918(81)90004-4

*Smith, A. P., Jones, D. M., & Broadbent, D. E. (1981). The effects of noise on recall of categorized lists. *British Journal of Psychology, 72,* 299–316. doi:10.1111/j.2044-8295.1981.tb02188.x

*Smith, A. P., & Miles, C. (1986). Acute effects of meals, noise and nightwork. *British Journal of Psychology, 77,* 377–387. doi:10.1111/j.2044-8295.1986.tb02204.x

*Smith, A. P., & Miles, C. (1987). The combined effects of occupational health hazards: An experimental investigation of the effects of noise, nightwork and meals. *International Archives of Occupational and Environmental Health, 59,* 83–89. doi:10.1007/BF00377682

*Smith, A. P, Whitney, H., Thomas, M., Perry, K., & Brockman, P. (1997). Effects of caffeine and noise on mood, performance and cardiovascular functioning. *Human Psychopharmacology: Clinical and Experimental, 12,* 27–33. doi:10.1002/(SICI)1099-1077(199701/02)12:1<27::AID-HUP827>3.0.CO;2-Y

*Smith-Jackson, T. L., & Klein, K. W. (2009). Open-plan offices: Task performance and mental workload. *Journal of Environmental Psychology, 29,* 279–289. doi:10.1016/j.jenvp.2008.09.002

Speaks, C. E. (1999). *Introduction to sound: Acoustics for the hearing and speech science* (3rd ed.). San Diego, CA: Singular.

*Standing, L. G., Verpaelst, C. C., & Ulmer, B. K. (2008). A demonstration of nonlinear demand characteristics in the "Mozart effect" experimental paradigm. *North American Journal of Psychology, 10,* 553–566.

*Starnes, W. R., & Loeb, R. C. (1993). Locus of control differences in memory recall strategies when confronted with noise. *Journal of General Psychology, 120,* 463–471. doi:10.1080/00221309.1993.9711160

*Surprenant, A. M. (1999). The effect of noise on memory for spoken syllables. *International Journal of Psychology, 34,* 328–333. doi:10.1080/002075999399648

*Surprenant, A. M., Neath, I., & LeCompte, D. C. (1999). Irrelevant speech, phonological similarity, and presentation modality. *Memory, 7,* 405–420. doi:10.1080/741944920

*Tafalla, R. J., & Evans, G. W. (1997). Noise, physiology, and human performance: The potential role of effort. *Journal of Occupational Health Psychology, 2,* 148–155. doi:10.1037/1076-8998.2.2.148

*Taylor, W., Melloy, B., Dharwada, P., Gramopadhye, A., & Toler, J. (2004). The effects of static multiple sources of noise on the visual search component of human inspection. *International Journal of Industrial Ergonomics, 34,* 195–207. doi:10.1016/j.ergon.2004.04.002

Thayer, R. E. (1978). Toward a psychological theory of multidimensional activation (arousal). *Motivation and Emotion, 2,* 1–34. doi:10.1007/BF00992729

Thayer, R. E. (1989). *The psychobiology of mood and arousal.* Oxford, England: Oxford University Press.

*Tikuisis, P., Ponikvar, M., Keefe, A. A., & Abel, S. M. (2009). Target detection, identification, and marksmanship during battlefield noise in a synthetic environment. *Military Psychology, 21,* 186–199. doi:10.1080/08995600902768735

*Tolan, G. A., & Tehan, G. (2002). Testing feature interaction: Between-stream irrelevant speech effects in immediate recall. *Journal of Memory and Language, 46,* 562–585. doi:10.1006/jmla.2001.2820

*Tremblay, S. B., & Jones, D. M. (1998). Role of habituation in the irrelevant sound effect: Evidence from the effects of token set size and rate of transition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 659–671. doi:10.1037/0278-7393.24.3.659

*Tremblay, S. B., MacKen, W. J., & Jones, D. M. (2001). The impact of broadband noise on serial memory: Changes in band-pass frequency increase disruption. *Memory, 9,* 323–331. doi:10.1080/09658210143000010

*Tremblay, S. B., Nicholls, A. P., Alford, D., & Jones, D. M. (2000). The irrelevant sound effect: Does speech play a special role? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1750–1754. doi:10.1037/0278-7393.26.6.1750

*Trimmel, M., & Poelzl, G. (2006). Impact of background noise on reaction time and brain DC potential changes of VDT-based spatial attention. *Ergonomics, 49,* 202–208. doi:10.1080/00140130500434986

*Van Gemmert, A. W. A., & Van Galen, G. P. (1997). Stress, neuromotor noise, and human performance: A theoretical perspective. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1299–1313. doi:10.1037/0096-1523.23.5.1299

*Van Gemmert, A. W. A., & Van Galen, G. P. (1998). Auditory stress effects on preparation and execution of graphical aiming: A test of the neuromotor noise concept. *Acta Psychologica, 98,* 81–101. doi:10.1016/S0001-6918(97)00049-8

*Veitch, J. A. (1990). Office noise and illumination effects on reading comprehension. *Journal of Environmental Psychology, 10,* 209–217. doi:10.1016/S0272-4944(05)80096-9

*von Wright, J., & Vauras, M. (1980). Interactive effects of noise and neuroticism on recall from semantic memory. *Scandinavian Journal of Psychology, 21,* 97–101. doi:10.1111/j.1467-9450.1980.tb00346.x

*Warner, H. D., & Heimstra, N. W. (1972). Effects of noise intensity on visual target-detection performance. *Human Factors, 14,* 181–185.

*Weinstein, N. D. (1974). Effect of noise on intellectual performance. *Journal of Applied Psychology, 59,* 548–554. doi:10.1037/h0037338

*Weisz, N., & Schlittmeier, S. J. (2006). Detrimental effects of irrelevant speech on serial recall of visual items are reflected in reduced visual N1 and reduced theta activity. *Cerebral Cortex, 16,* 1097–1105. doi:10.1093/cercor/bhj051

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3,* 159–177. doi:10.1080/14639220210123806

*Wilding, J., & Mohindra, N. (1980). Effects of subvocal suppression, articulating aloud and noise on sequence recall. *British Journal of Psychology, 71,* 247–261. doi:10.1111/j.2044-8295.1980.tb01742.x

*Wilding, J., Mohindra, N., & Breen-Lewis, K. (1982). Noise effects in free recall with different orienting tasks. *British Journal of Psychology, 73,* 479–486. doi:10.1111/j.2044-8295.1982.tb01829.x

*Wohlwill, J. F., Nasar, J. L., DeJoy, D. M., & Foruzani, H. H. (1976). Behavioral effects of a noisy environment: Task involvement versus passive exposure. *Journal of Applied Psychology, 61,* 67–74. doi:10.1037/0021-9010.61.1.67

*Wong, P. C. M., Jin, J. X., Gunasekera, G. M., Abel, R., Lee, E. R., & Dhar, S. (2009). Aging and cortical mechanisms of speech perception in noise. *Neuropsychologia, 47,* 693–703. doi:10.1016/j.neuropsychologia.2008.11.032

*Woodhead, M. M. (1964). The effect of bursts of noise on an arithmetic task. *American Journal of Psychology, 77,* 627–633. doi:10.2307/1420774

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