**Auditory distraction during reading: A Bayesian meta-analysis of a continuing controversy**

**Martin R. Vasilev**

Abstract

It has long been argued

In the current study, we report a meta-analytical investigation of k number of studies on auditory distraction effects during reading spanning over 80 years.

*Keywords*: auditory distraction, reading, background noise, speech, music

Reading is a critical skill that is indispensable in modern society. Although reading performance is best in silence when no distracting stimuli are present, such ideal conditions are rarely typical for daily life. Rather, much of everyday reading occurs in the presence of external auditory stimulation, such as noise from nearby traffic, music playing in the background, or a colleague talking on the phone. The interest in how auditory stimuli affect human performance is almost as old as modern psychology itself (e.g. Cassel & Dallenbach, 1918; Morgan, 1917). From to the widespread use of personal radios among students in the 1940s (Henderson, Crews, & Barlow, 1945; Miller, 1947) to the rise in popularity of the TV (Armstrong, Boiarsky, & Mares, 1991; Cool, Yarbrough, Patton, Runde, & Keith, 1994) and mobile devices (Kallinen, 2002), researchers and educators alike have been interested in whether background sounds can distract students from reading and other study-related tasks.

Over the past eight decades, many studies have examined how experimental exposure to speech, noise, and music affects the reading process. Although some important patterns of results have emerged, the research literature has been undermined by a fair amount of inconsistent findings and the general lack of broader theoretical frameworks that can explain how auditory distraction during reading occurs. Although a number of theoretical accounts have been developed in simpler tasks such as serial recall, it is currently not known how well they can account for all the findings from reading comprehension tasks that have been accumulated over the past several decades. Additionally, due to the mixed findings in some areas, it is currently not well understood what the magnitude of auditory distraction effects is.

In the present paper, we address these issues in two ways. First, we present the first attempt to make a statistical synthesis of previous findings in a reading task in order to find out whether, and to what extent, auditory stimuli can interfere with reading performance. To do this, we adopted a Bayesian meta-analysis approach that makes it possible to quantify the degree of belief, given the data, that background sounds can disrupt reading. Second, we used Bayesian meta-regression models to test the predictions derived from existing theories on auditory distraction and to estimate how likely it is that they can explain the available data. The present paper starts with a brief overview of the literature that highlights existing inconsistencies. Then, we consider theories that can explain auditory distraction effects during reading. Finally, the predictions from these theories are outlined and tested.

**The effect of background noise, speech, and music on reading: An overview**

**Background noise.** Although a number of epidemiological studies have suggested that chronic exposure to noise is associated with lower reading ability in children (e.g., Haines, Stansfeld, Job, Berglund, & Head, 2001; Hygge, Evans, & Bullinger, 2002; Papanikolaou, Skenteris, & Piperakis, 2015; Stansfeld et al., 2005), only few studies have examined the effect of experimental exposure to noise. In one early study, Johansson (1983) found that 10-year-old children had the same reading comprehension and reading speed under quiet conditions, and conditions of continuous, or intermittent acoustic noise. More recently, Dockrell and Shield (2006) investigated the effect of typical classroom noise on reading comprehension in 8-year-old children. Participants completed the Suffolk Reading Scale in one of three conditions: silence, noise consisting of childrens’ babble, and the same babble combined with intermittent environmental noise. The results showed that children performed better in quiet than in the babble noise condition. Surprisingly however, reading performance was best when babble was combined with environmental noise. Using similar sound stimuli, Ljung, Sorqvist, and Hygge, (2009) found that road traffic noise impaired the reading speed of 12-13-year-old children, but not their reading comprehension. However, a condition of children’s babble intermixed with irrelevant speech affected neither measure.

Studies of exposure to noise in adults have resulted in similarly mixed findings, sometimes even when done with the same materials (cf. Martin, Wogalter, & Forlano, 1988, Experiments 4 and 5). While most studies have failed to find an effect of noise on reading comprehension (Gawron, 1984; Jahncke, Hygge, Halin, Green, & Dimberg, 2011; Johansson, Holmqvist, Mossberg, & Lindgren, 2012; Veitch, 1990), others have found such an effect after examining the mediating role of personality characteristics (Furnham, Gunter, & Peterson, 1994; Ylias & Heaven, 2003). In summary, studies investigating the effect of background noise on reading comprehension have yielded inconsistent results, although some of them have suggested that exposure to noise may be detrimental.

**Background speech.** Similar to noise, background speech is also often a nuisance to readers. However, speech has different acoustic properties than noise and it also carries semantic meaning if readers are able to understand it (which is very often the case in daily life). Perhaps owing to its semantic content, background speech is often rated as more distracting and more annoying than acoustic noise (Haka et al., 2009; Haapakangas et al., 2011; Landström, Söderberg, Kjellberg, & Nordström, 2002). Consistent with this subjective perception, meaningful background speech has been found to disrupt reading comprehension in a number of experiments (Armstrong et al., 1991; Baker & Madell, 1965; Martin et al., 1988; Sörqvist, Halin, & Hygge, 2010; however, see Venetjoki, Kaarlela-Tuomaala, Keskinen, & Hongisto, 2006). Additionally, there is some evidence to suggest that this disruption effect may be larger for participants who have poorer immediate suppression mechanism to ignore the background speech (Sörqvist, Halin, & Hygge, 2010; Sörqvist, Ljungberg, & Ljung, 2010).

Due to its implications for performance at the workplace, the effect of background speech on proofreading has also been investigated. Proofreading is a more cognitively demanding task than reading because it also requires allocating attention to look for mistakes, in addition to reading the text. There are generally two types of mistakes that have been considered in proofreading studies: contextual mistakes that require understanding the meaning of the text in order to detect, and non-contextual (i.e. spelling) mistakes that require only processing of the current word to detect. Due to the semantic content of speech, it can be hypothesized that background speech would disrupt the detection of contextual errors more than the detection of non-contextual errors.

Some support for this prediction was found by an early study by Weinstein (1977) who reported that background speech consisting of radio news significantly impaired the detection of contextual, but not the detection of non-contextual errors. However, Jones, Miles, and Page (1990) found exactly the opposite effect in another study. The authors manipulated both by the intelligibility of background speech (normal vs reversed) and the intensity of the sound (50 vs 70 dBA). They found that the intensity of the sound did not affect proofreading performance, but that normal (i.e. intelligible) speech reduced the number of non-contextual errors that were detected. Critically, however, the intelligibility of speech did not affect the detection of contextual errors (Jones et al., 1990). More recently, Venetjoki et al. (2006) found that background speech compared to continuous noise reduced the overall accuracy on the proofreading task. However, even though the task included both contextual and non-contextual errors, there was no significant effect of background speech on either error type in isolation. In a similar study, Landström et al. (2002) found that background speech, compared to broadband noise, did not affect proofreading performance for either contextual or non-contextual mistakes. The background stimuli were presented at comparable sound levels to Venetjoki et al. (2006), although the speech consisted of random statements. Finally, Smith-Jackson and Klein (2009) also found no effect of background speech (intermittent or continuous) on overall proofreading accuracy.

Interestingly, a few studies have also suggested that the detrimental effect of background speech on reading and proofreading can be diminished by making the task harder and thus increasing participants’ engagement with it (Halin, 2016; Halin, Marsh, Haga, Holmgren, & Sörqvist, 2014a; Halin, Marsh, Hellman, Hellström, & Sörqvist, 2014b). In a few experiments, Halin et al. showed that performance on a reading/ proofreading task was disrupted by background speech only when the text was formatted in a familiar, but not in an unfamiliar (i.e. more difficult to read) font, and when the text was printed normally, but not when it was visually degraded (i.e. harder to read). Therefore, these results suggest that increasing task engagement may decrease the detrimental effect of background speech on reading comprehension and proofreading accuracy (see Sörqvist & Marsh, 2015 for a discussion).

The majority of studies that were considered so far have investigated only the end product of reading (i.e., comprehension accuracy or the overall time taken to read the text). However, these studies do not tell us how the reading process is influenced on a moment-to-moment basis. More recently, a number of eye-tracking studies have addressed this question by showing that the effect of background speech on reading can also be found at the level of fixation durations and fixations probabilities (Cauchard, Cane, & Weger, 2012; Hyönä & Ekholm, 2016; Vasilev, Liversedge, Rowan, Kirkby & Angele, 2017) One of the key finding from these studies is that background speech leads to an increased number of re-reading fixations. While these studies have been successful in explaining where in the reading process disruption by background speech occurs, one puzzling aspect is that, unlike behavioural studies, none of the eye-tracking experiments replicated the effect of disruption in comprehension accuracy. It is currently not known why this inconsistency exists, but it does raise the question of how reliable the effect of background speech on reading comprehension is.

In summary, background speech has been found to disrupt reading comprehension and proofreading accuracy in a number of experiments. In addition, the available evidence suggests that this disruption is due to processing the semantic meaning of the speech sound. These effects appear to be more consistent than the effect of background noise on reading, which has not been consistently replicated. Nevertheless, the effect of background speech on reading comprehension has also had its fair share of null effects, particularly in recent years, which casts doubt on its robustness.

**Background music.** Unlike noise and speech, playing music in the background is often a personal choice or a habit. Interest in the potential effect of background music on reading started in the first half of the 20th century with the popularity of personal radios and their use by students. However, these early studies did not paint a clear picture of the relationship between background music and reading. While some of them found that music can disrupt reading comprehension in children and university students (Henderson et al., 1945; Fendrick, 1937; Fogelson, 1973), others found that background music either does not affect reading (Freeburne & Fleischer, 1952; Miller, 1947; Mitchell, 1949) or that it actually improves it (Hall, 1952). Indeed, this controversy has persisted until the present day, and even the only two eye-tracking studies to address this question (Cauchard et al., 2012; Johansson et al., 2012) have failed to find any effect of background music on fixation durations and fixation probabilities.

In order to examine what conditions may give rise to distraction,somestudies have investigated whether the effect of background music on reading comprehension is modulated by personality traits (Avila, Furnham, & McClelland, 2011; Furnham & Allass, 1999; Furnham & Bradley, 1997; Furnham, Trew, & Sneade, 1999; Furnham & Stephenson, 2007; Furnham & Strbac, 2002). Based on Eysenck’s (1967) theory of personality, these studies have predicted that individuals high in extraversion will be distracted less by background music than individuals high in introversion due to extroverts’ higher cortical arousal threshold. However, the results from these studies have been mixed. While some studies found such an interaction between personality trait and background music (Daoussis & McKelvie, 1986; Furnham & Bradley, 1997; Furnham & Strbac, 2002), others did not (Avila et al., 2011; Furnham & Allass, 1999; Furnham et al., 1999; Furnham & Stephenson, 2007). A number of factors may have led to these inconsistencies, such as the way in which participants were classified as introverts and extroverts, and the small sample size in some of the studies.

Another factor that has been considered is the genre of the music (Kallinen, 2002; Miller & Schyb, 1989; Tucker & Bushman, 1991). However, as the popularity of music genres changes with time, it is arguably better to investigate what aspects of the music may cause distraction. One factor that may play a role is participants’ preference for the music. For example, Etaugh and colleagues (Etaugh & Michals, 1975; Etaugh & Ptasnik, 1982) reported that preferred music decreased reading comprehension scores, but only for students who seldom study with music. In contrast to this, Johansson et al. (2012) found that participants had lower comprehension accuracy when listening to non-preferred music, but there was no effect of preferred music. Participants’ studying habits also did not modulate the results. Adding further to the confusion, Perham and Currie (2014) found that both liked and disliked lyrical music is equally disruptive to reading comprehension, although they did not report data on students’ studying habits.

The influence of background music on reading may also be modulated by the acoustic properties of the music. Some factors that have been considered are its informational load (Kiger, 1989), loudness and tempo (Thompson, Schellenberg, & Letnic, 2012), familiarity to participants (Hilliard & Tolin, 1979) and its capability to induce a startle response (Ravaja & Kallinen, 2004). These results are quite interesting in understanding what types of music may cause distraction, although they would benefit from further replication and extensions. In summary, previous studies suggest that certain types of music may be distracting, although a negative effect of background music on reading performance has not been consistently observed.

To summarize the discussion so far, the available evidence, mostly from behavioural measures, suggests that experimental exposure to background noise, speech, and music may disrupt reading comprehension.

**Theories of auditory distraction**

One of the earliest theoretical accounts of auditory distraction effects is the *phonological interference* hypothesis. This account is based on Baddeley & Hitch’s (1974; 1994) model of working memory, in which the phonological loop acts as an acoustic store where memories are registered and rehearsed through a process of sub-vocalization. Salamé and Baddeley (1982; 1987; 1989) reported a series of experiments in which they showed that memory for visually presented digits is impaired by unattended speech, but not by unattended acoustic noise. Additionally, a disruption effect was observed even if the speech sound was in a language that participants could not understand (Salamé and Baddeley, 1987). The authors argued that this is because speech sounds automatically gain access to the phonological loop and thus interfere with the encoding of visually presented items. Although this hypothesis is derived from a memory task, Salamé and Baddeley (1989) argued that a similar disruption may also be observed in more complex cognitive tasks such as reading.

Martin et al. (1988) were first to systematically test the phonological disruption hypothesis in a reading comprehension task. In a series of experiments, they found that the disruptive effect of unattended speech was due to the semantic properties (i.e. meaning) of the speech, rather than its phonological features. More specifically, the authors found that English speech (intelligible to participants) was more distracting that Russian speech (unintelligible to participants). Similarly, a continuous speech stream of random words was found to disrupt comprehension more than a continuous speech stream of non-words. To account for these results, Martin et al. (1988) argued that, unlike serial recall tasks, reading comprehension requires understanding the meaning of the text. Therefore, the semantic properties of the irrelevant speech can interfere with building the semantic representations of the text that is being read. This prediction will be referred to as the *semantic interference* hypothesis.

The *changing-state* hypothesis (Hughes & Jones, 2001; Jones & Macken, 1993; Jones, Madden, & Miles, 1992) is another prediction that is also derived from serial recall tasks. According to this hypothesis, interference is caused by background sounds that exhibit considerable acoustic variation, but not by steady-state, aperiodic sounds that do not have such variation (Jones et al., 1992). For example, a sound consisting of different consonants (e.g., “B”, “F”, “P”, “S”, “N”) should cause more interference than a sound made up of the same consonant (e.g., “M, M, M, M, M”) because it exhibits more acoustic variation. The hypothesized mechanism through which interference occurs is that changing-state sounds contain information about the serial order of the constituent sounds (Hughes & Jones, 2001). This information in turn can interfere with maintaining the serial order of items in a memory task.

Although reading may pose different task demands, it also involves maintaining the order of words in the sentence, as well as their syntactic relations. For example, models of parallel word processing such as the SWIFT model (Engbert, Nuthmann, Richter, & Kliegl, 2005) assume, at least implicitly, that readers are somehow able to maintain word-order information while processing multiple words at the same time. Similarly, cue-based retrieval models of sentence comprehension (e.g. ) involve storing syntactic cues about. These cues are by necessity also stored in blah-blah.

A final account that is relevant in a reading task is the *duplex theory* of auditory distraction (Hughes, 2014; Hughes, Vachon, & Jones, 2005; 2007; Sörqvist, 2010). According to this theory, auditory distraction can occur from two different processes: *interference-by-process* and *attentional capture* (Hughes, 2014). Interference-by-process (Marsh, Hughes, & Jones, 2008; 2009; Marsh & Jones, 2010) occurs when the background sound interferes with a process that is important for the main task. For example, in a reading task, the semantic processing of meaningful speech would interfere with the task because reading also requires semantic processing to extract the meaning of the text. Alternatively, auditory distraction can also be caused by attentional capture (Hughes et al., 2005; Vachon, Hughes, & Jones, 2012) where attention is temporally directed away from the main task. For example, the sound “B” in the sequence “AAAAAA**B**A” would capture attention because another “A” is expected in the sequence (Hughes, 2014).

The present investigation does not make it possible to distinguish between the disruption by process or disruption by process accounts. However, we will return to this issue in the discussion.

Although attentional capture is a very interesting concept, it more difficult to study in longer tasks such as reading that typically involve long exposure to sounds.

1. **Phonological interference** (Salamé, & Baddeley, 1982; 1987; 1989)

Previous studies using a reading comprehension task have provided little or no support for a role in phonology in interference by background speech (Hyönä & Ekholm, 2016, Experiment 1; Martin, Wogalter, & Forlano, 1988; Vasilev, Liversedge, Rowan, Kirkby, & Angele, 2017).

1. **Semantic interference** (Martin, Wogalter, & Forlano, 1988)
2. **Interference-by-process** (Marsh, Hughes, & Jones, 2009; Marsh & Jones, 2010).
3. **Duplex theory** (attentional capture/ interference process) (Hughes, 2014)
4. **Changing state hypothesis** (Hughes & Jones, 2001; Jones, Madden, & Miles, 1992)- originally developed in serial memory task, which shows ISE. However, it can be argued that reading also involves maintaining serial relationships between words. For example, models of parallel word processing such as SWIFT assume, at least implicitly, that readers are somehow able to maintain word-order information while processing multiple words at the same time.
5. **Predictions**

Since most of the theories outlined above were not originally developed in a reading comprehension task, it is important to note that the present investigation is not a strict test of the theories. Rather, it aims to find out whether, and to what extent, they can accommodate the existing evidence in reading tasks.

Whether the nature of the disruption is content-based or processed-based is beyond the scope of the present investigation. However, we will return to this question in the Discussion.

Because the content of the irrelevant speech is often not related to the content of the text that participants are reading (see for an exception), interference-by-process makes the same prediction as the

**Hypothesis 1 (phonological interference):**

According to the phonological interference account, speech that is completely unintelligible to participants (e.g. in a foreign language) should be just as disruptive as

speech that is intelligible to them (i.e., in their native language).

In its strictest form, the phonological disruption hypothesis would also predict that intelligible speech would be more disruptive than lyrical music. The reason for this is that lyrical music would, on average, contain less speech and therefore less phonological information than a continuous stream of speech.

Comparisons (descriptive/ general purpose):

General (all sound)- acc & speed

General (music)- acc

General (speech)- acc

General (noise)- acc

Theoretical:

* Lyrical vs non-lyrical music (semantic/phonological): argue that phonological contribution is possible; however, several studies so far have failed to provide evidence for a central role of phonology in a reading task
* Lyrical music vs speech (phonological): because on average music contains less phonological information compared to speech (however, both contain semantics/ meaning).
* Changing state hypothesis: acoustic noise (e.g. hissing vs instrumental music). Music will be more variable than random/ white noise; traffic, office etc. noise should be more disruptive by Gaussian/ white noise.
* Attentional capture: think about which sounds would be more attentionally capturing; try to find some references
* Interference by process: noise and (non-lyrical music) vs speech and lyrical music; former should not disrupt reading at all since music/ noise processing is irrelevant

The purest test of the changing-state hypothesis is comparing non-speech steady state sounds (e.g. white noise) to non-speech sounds that show greater acoustical variation (e.g. non-vocal music).

Notes:

Not enough studies for foreign vs native

Although it is sometimes assumed that results from different tasks and cognitive domains may extend to other tasks and domain, this is not necessarily the case.

Citations for: speech is perceived as distracting by office workers (see Haapakangas et al., 2014)

Last few decades have seen the emergence of a broad literature field that has focused on more fundamental skills such as working memory and serial recall. There have been some consistent findings and also theories have been developed to account for these results.

However, more complex cognitive tasks such as reading have received mixed findings. Additionally, it is not known whether findings from simple tasks such as serial recall would generalise to reading. Reading is appealing because it is easier to generalise to everyday tasks- how working memory is used in daily life is more difficult to say.

What we try here is to examine the potential of these theories to explain if, and what types of sounds are distracting during reading. It is necessary to consider theories that make the same predictions and are hard to distinguish from one another based on present findings.

**Present Study**

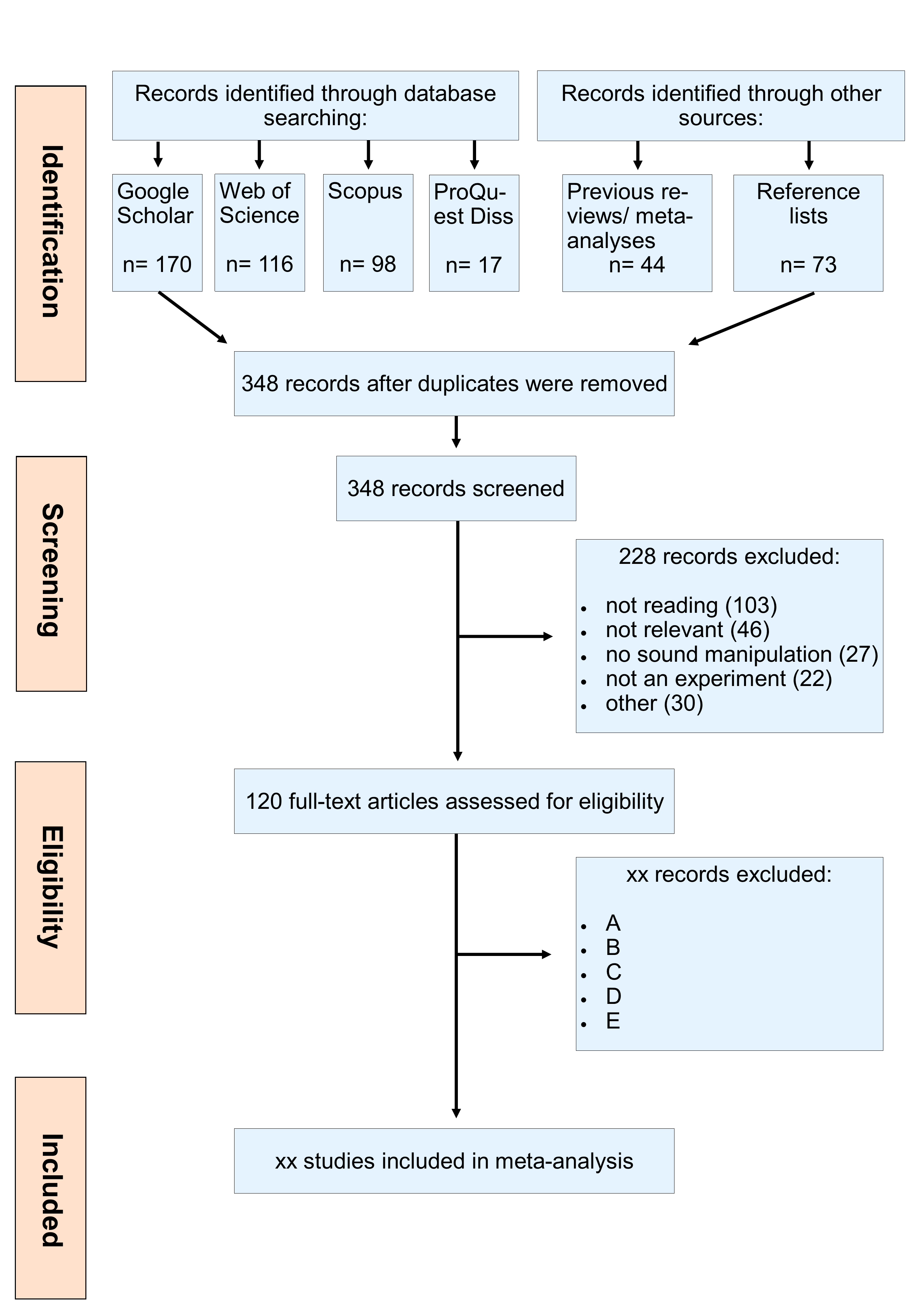
The inconsistent results raise the question of how much distraction, if any, is incurred in the reading process by different sounds when all the available evidence is taken into account. Bayesian is ideally suited to tackle controversial issues as it directly computes the probability of blah-blah.

Bayesian meta-analytical models have traditionally been used in biology and medicine (e.g. Sutton & Abrams, 2001; Sutton et al. 2000), but more recently have also been introduced to psychology and linguistics (Vasishth, 2015; Vasishth, Chen, Li, & Guo, 2013; Jäger, Engelmann, & Vasishth, 2017).

**Method**

**Literature Search**

The search of the literature was conducted by following the PRISMA guidelines (Moher, Liberati, Tetzlaff, Altman, & Prisma Group, 2009). A flowchart of the process is presented in Figure 1[[1]](#footnote-1). In August 2016, Google Scholar, Scopus, the Web of Science, and ProQuest Dissertations were searched with the following keywords: “background noise AND reading”, “background speech AND reading”, “background music AND reading”. The search for each of the three background sounds was done separately. Additionally, the reference list of screened articles and previous literature reviews and meta-analyses (Beaman, 2005; Clark & Sörqvist, 2012; Dalton, & Behm, 2007; Kämpfe, Sedlmeier, & Renkewitz, 2010; Klatte, Bergström, & Lachmann, 2013; Shield & Dockrell, 2003; Szalma & Hancock, 2011) were also examined. The identified articles were evaluated against the inclusion criteria presented in Appendix A. In short, the studies had to experimentally manipulate background noise, speech or music in a reading or proofreading task, have a sound methodological design, and include silence as a baseline reading condition. Information about the included studies and their effect sizes are presented in Appendix B.



*Figure 1*. A flowchart illustrating the stages of the literature search process.

**Effect Size Calculation**

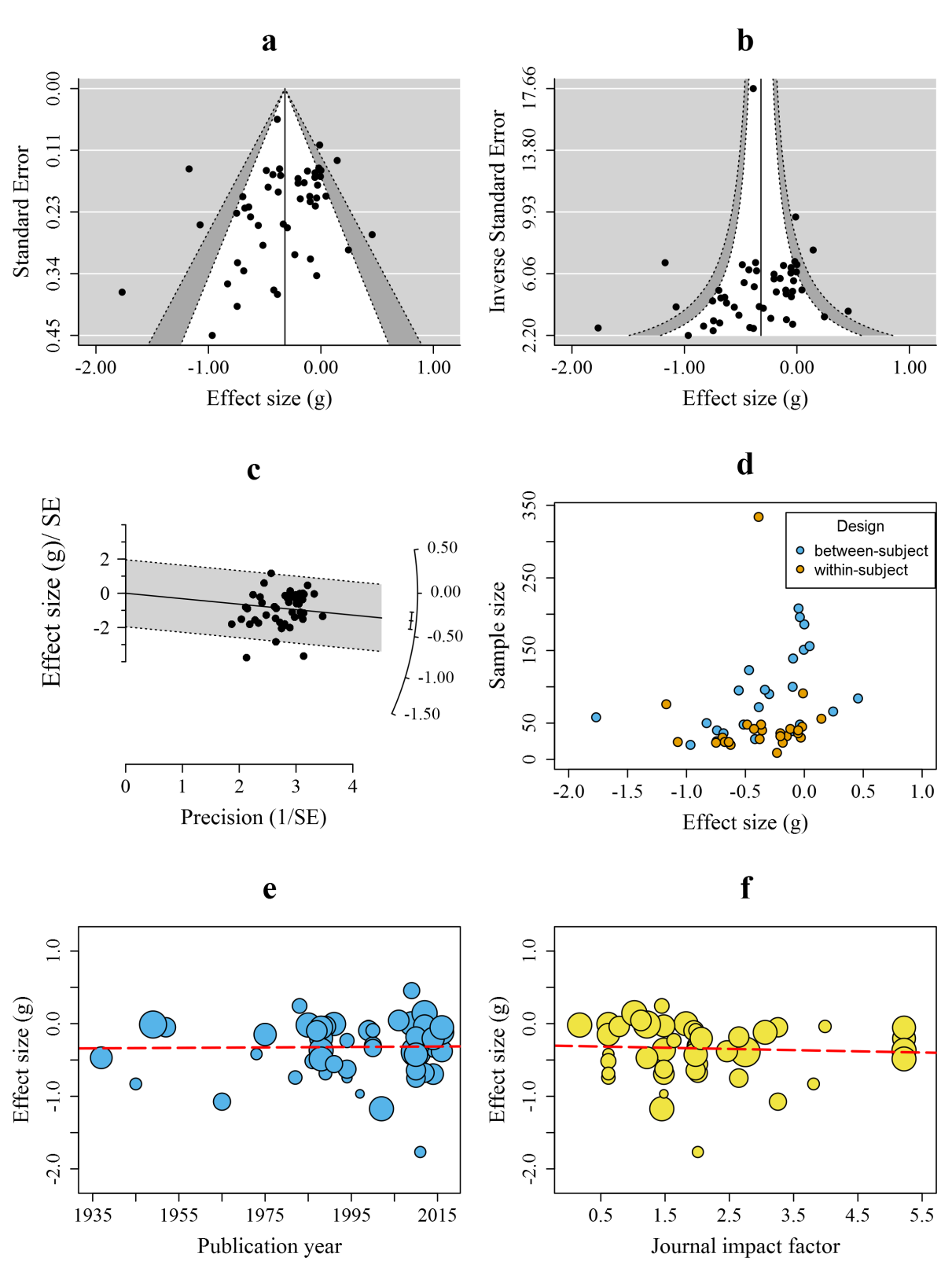
Standardized effect sizes of the mean difference were calculated from the reported descriptive statistics by first calculating Cohen’s *d* and then applying Hedges’ *g* (Hedges & Olkin, 1985) correction for small sample bias. This was done using formulas 12.11-12.22 from Borenstein (2009). If descriptive statistics were unavailable or incomplete, the effect sizes were calculated by digitalizing graphs (Rohatgi, 2015) or converted/approximated from the reported test statistics by using existing formulas (Borenstein, 2009; Lajeunesse, 2013). In the analysis of reading comprehension accuracy and proofreading accuracy, studies were coded so that negative effect sizes indicate lower comprehension accuracy in the experimental sound conditions. Similarly, in the analysis of reading speed, negative effect sizes also indicate slower reading speed in the experimental sound conditions.

Due to the fact that xx% of the studies used a within-subject design, it was necessary to estimate the population correlation (ρ) between the control and experimental conditions. (Borenstein, 2009; Szalma & Hancock, 2011). Eight statistically-independent estimates were obtained from experiments for which the raw data were available, as well as from one study (Miller, 1947) that reported the required statistics. These represented a wide range of experimental sound types and included both reading comprehension and reading speed measures. We followed Szalma and Hancock’s (2011) approach to meta-analyze the obtained correlations and obtain a weighted estimate of ρ. The weighted value of 0.74 was used for calculating the effect sizes for within-subject design studies.

**Publication Bias**

Xx% of the studies included in the present meta-analysis were in the grey literature (i.e. they were not formally published in a peer-reviewed journal or an edited book).

A test of funnel plot asymmetry based on a weighted linear regression of the effect estimates on their standard errors (Sterne et al., 2011) indicated no statistically significant evidence for asymmetry for both reading comprehension () and reading speed ().



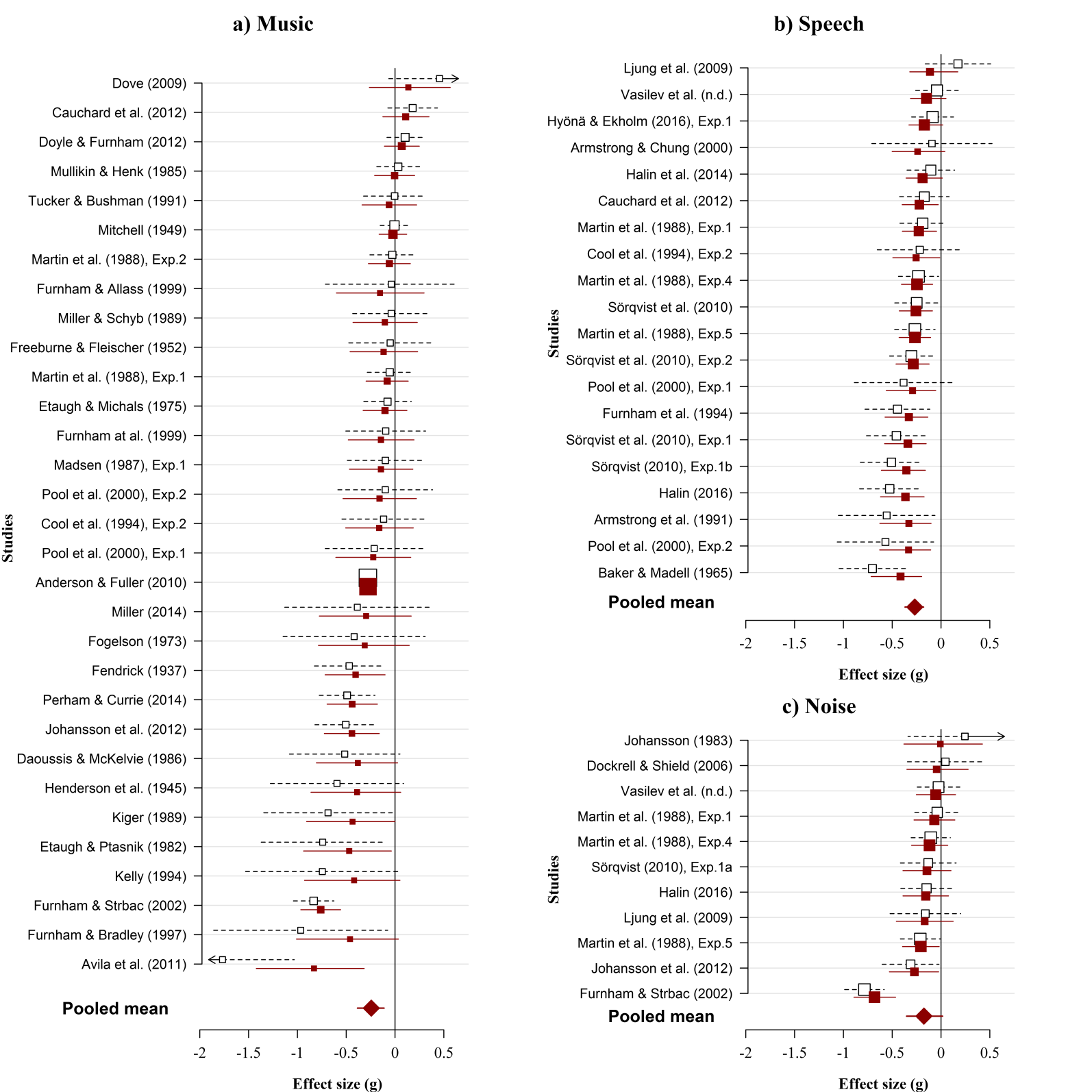
*Figure x*. Visual assessment of publication and related biases for reading comprehension accuracy (presentation format adapted from Nakagawa, Noble, Senior, & Lagisz, 2017, Figure 6). **a** White and dark grey bounds indicate respectively 95% and 99% pseudo-confidence intervals.

**Data Analysis**

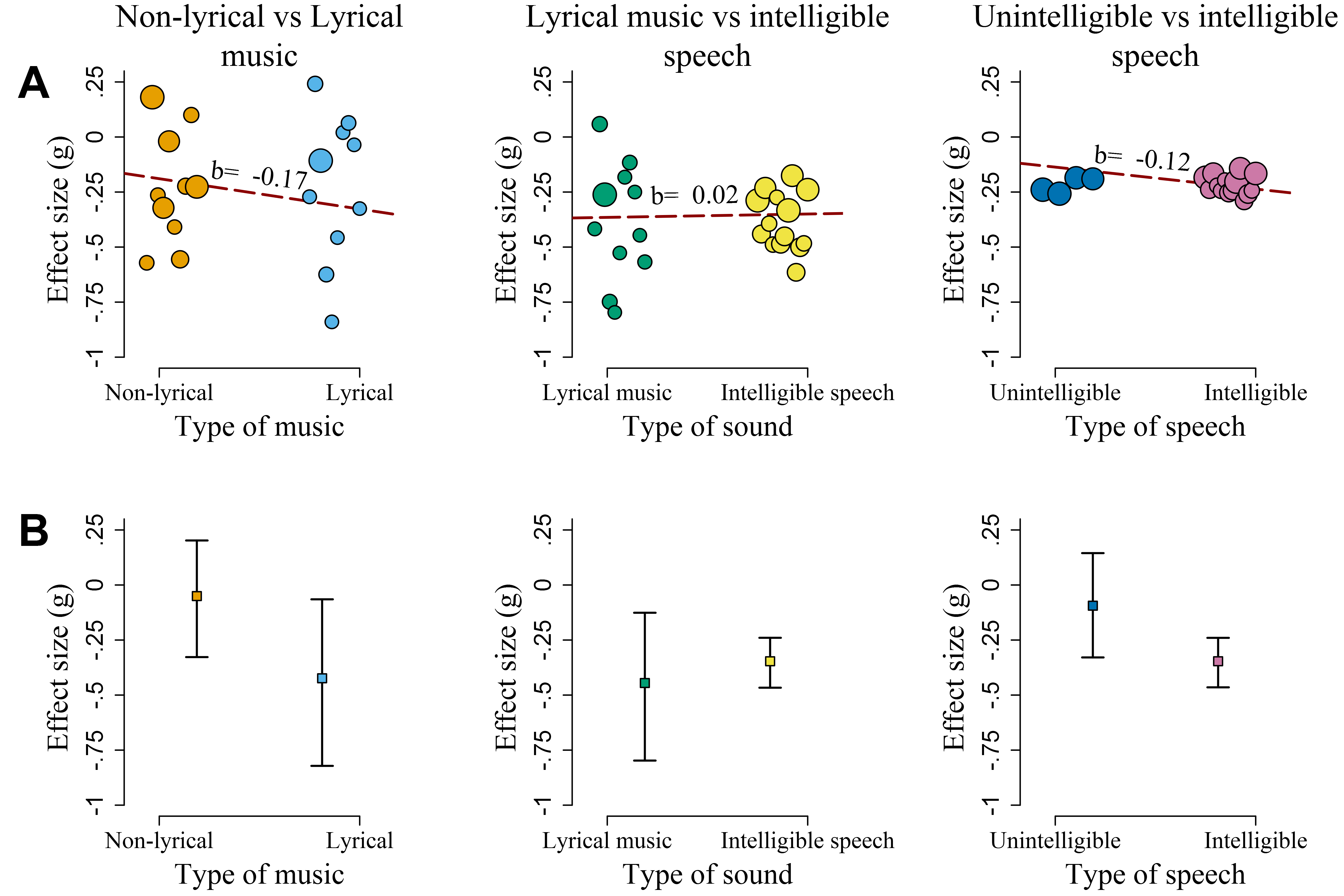
Add a table with the meta-regression contrasts.

**Results**

**Meta-analysis**

*****Figure x*. Forest plot for the main effect of background music (**a**), speech (**b**), and noise (**c**) on reading comprehension. Dark red squares and error bars show the posterior estimate of the study effect from the meta-analysis model and the corresponding 95% CrIs. Open squares and dashed error bars show the observed (i.e. empirical) effect size and the 95% CIs. The size of the squares is proportional to the weight of each study (i.e., the inverse of the variance of the sampling distribution). The pooled estimate from the meta-analysis is shown by the dark red diamond at the bottom of each panel (with 95% CrIs).

**Meta-regression**



*Figure x*. Results of the meta-regression models testing the predictions of semantic and/or phonological disruption hypotheses. Panel **A** shows the regression slope and the studies included the in the analysis. The slope indicates the estimated mean effect size difference (in terms of Hedges’s g) between the two groups. The size of circles is proportional to the weight of individual studies (inverse of the variance of the sampling distribution). Panel **B** shows the posterior effect size for each group, as estimated by a meta-analysis of the simple effect. Error bars show the 95% credible intervals.

Mention that meta-regression results are adjusted for the precision of individual studies.

**Discussion**

**Acknowledgments**

M.R.V was supported by a PhD studentship from Bournemouth University on the topic of this paper. The funding body had no role in the design, analysis, the writing of this paper, or decisions to publish. The authors declare no conflicts of interest with respect to this paper. All data analysis scripts and materials are available during the peer-review process at: https: and will be made publicly available at GitHub and the Open Science Framework upon the publication of this meta-analysis.

**Appendix A**

**Appendix B**

Table B1

*A Summary of the Studies and Their Effect Sizes That Were Included in the Meta-analysis*

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ID | Study | NC | NE | Sample | Design | DV | Sound | Sound type | dB(A) | g | var |
| 1 | Sörqvist et al. 2010 | 40 | | adults | within | RC | speech | native | 72.5 |  |  |
| 1 | Sörqvist et al. 2010 | 40 | | adults | within | RS | speech | native | 72.5 |  |  |
| 2 | Ljung et al. 2009 | 70 | 50 | children | between | RC | noise | traffic | 62 |  |  |
| 2 | Ljung et al. 2009 | 70 | 50 | children | between | RS | noise | traffic | 62 |  |  |
| 2 | Ljung et al. 2009 | 70 | 66 | children | between | RC | speech | babble | 62 |  |  |
| 2 | Ljung et al. 2009 | 70 | 66 | children | between | RS | speech | babble | 62 |  |  |
| 3 | Fogelson 1973 | 14 | 14 | children | between | RC | music | pop | - |  |  |
| 4 | Tucker & Bushman 1991 | 75 | 76 | adults | between | RC | music | rock & roll | 80 |  |  |
| 5 | Daoussis & McKelvie 1986 | 24 | 24 | adults | between | RC | music | rock | 50 |  |  |
| 6 | Etaugh & Michals 1975 | 32 | | adults | within | RC | music | preferred | - |  |  |
| 7 | Etaugh & Ptasnik 1982 | 20 | 20 | adults | between | RC | music | preferred | - |  |  |
| 8 | Kiger 1989 | 18 | 18 | children | between | RC | music | low load | - |  |  |
| 8 | Kiger 1989 | 18 | 18 | children | between | RC | music | high load | - |  |  |
| 9 | Miller & Schyb 1989 | 49 | 49 | adults | between | RC | music | classical | 47.5 |  |  |
| 9 | Miller & Schyb 1989 | 49 | 49 | adults | between | RC | music | pop | 47.5 |  |  |
| 9 | Miller & Schyb 1989 | 49 | 49 | adults | between | RC | music | vocal | 47.5 |  |  |
| 10 | Doyle & Furnham 2012 | 56 | | adults | within | RC | music | vocal | - |  |  |
| 11 | Anderson & Fuller 2010 | 334 | | children | within | RC | music | lyrical | 75 |  |  |
| 12 | Furnham & Strbac 2002 | 76 | | children | within | RC | noise | office | - |  |  |
| 12 | Furnham & Strbac 2002 | 76 | | children | within | RC | music | vocal/unfam. | - |  |  |
| 13 | Mullikin & Henk 1985 | 45 | | children | within | RC | music | classical | - |  |  |
| 13 | Mullikin & Henk 1985 | 45 | | children | within | RC | music | rock | - |  |  |
| 14 | Avila et al. 2011 | 19 | 20 | children | between | RC | music | vocal/ familiar | - |  |  |
| 14 | Avila et al. 2011 | 19 | 19 | children | between | RC | music | Instr./ familiar | - |  |  |
| 15 | Freeburne & Fleisch. 1952 | 43 | 46 | adults | between | RC | music | classical | - |  |  |
| 15 | Freeburne & Fleisch. 1952 | 43 | 46 | adults | between | RS | music | classical | - |  |  |
| 15 | Freeburne & Fleisch. 1952 | 43 | 42 | adults | between | RC | music | pop | - |  |  |
| 15 | Freeburne & Fleisch. 1952 | 43 | 42 | adults | between | RS | music | pop | - |  |  |
| 15 | Freeburne & Fleisch. 1952 | 43 | 40 | adults | between | RC | music | semi-classical | - |  |  |
| 15 | Freeburne & Fleisch. 1952 | 43 | 40 | adults | between | RS | music | semi-classical | - |  |  |
| 15 | Freeburne & Fleisch. 1952 | 43 | 37 | adults | between | RC | music | jazz | - |  |  |
| 15 | Freeburne & Fleisch. 1952 | 43 | 37 | adults | between | RS | music | jazz | - |  |  |
| 16 | Fendrick 1937 | 61 | 62 | adults | between | RC | music | semi-classical | - |  |  |
| 17 | Henderson et al. 1945 | 19 | 17 | adults | between | RC | music | classical | - |  |  |
| 17 | Henderson et al. 1945 | 19 | 14 | adults | between | RC | music | pop | - |  |  |
| 18 | Miller 2014 | 13 | 13 | adults | between | RC | music | classical lyrical | - |  |  |
| 18 | Miller 2014 | 13 | 17 | adults | between | RC | music | classical instr. | - |  |  |
| 18 | Miller 2014 | 13 | 11 | adults | between | RC | music | rock lyrical | - |  |  |
| 18 | Miller 2014 | 13 | 18 | adults | between | RC | music | rock instr. | - |  |  |
| 19 | Furnham & Allass 1999 | 16 | 16 | adults | between | RC | music | complex | - |  |  |

Table B1 (continued)

*A Summary of the Studies and Their Effect Sizes That Were Included in the Meta-analysis*

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ID | Study | NC | NE | Sample | Design | DV | Sound | Sound type | dB(A) | g | var |
| 19 | Furnham & Allass 1999 | 16 | 16 | adults | between | RC | music | simple | - |  |  |
| 20 | Furnham & Bradley 1997 | 10 | 10 | adults | between | RC | music | pop | - |  |  |
| 21 | Furnham at al. 1999 | 43 | 49 | children | between | RC | music | instrumental | - |  |  |
| 21 | Furnham at al. 1999 | 43 | 47 | children | between | RC | music | vocal | - |  |  |
| 22 | Perham & Currie 2014 | 30 | | adults | within | RC | music | disliked lyrical | 70 |  |  |
| 22 | Perham & Currie 2014 | 30 | | adults | within | RC | music | non-lyrical | 70 |  |  |
| 22 | Perham & Currie 2014 | 30 | | adults | within | RC | music | liked lyrical | 70 |  |  |
| 23 | Kelly 1994 | 13 | 12 | adults | between | RC | music | pop | 65 |  |  |
| 24 | Dove 2009 | 28 | 28 | adults | between | RC | music | sedat. classical | 62.5 |  |  |
| 24 | Dove 2009 | 28 | 28 | adults | between | RC | music | stimul. classical | 62.5 |  |  |
| 24 | Dove 2009 | 28 | 28 | adults | between | RS | music | sedat. classical | 62.5 |  |  |
| 24 | Dove 2009 | 28 | 28 | adults | between | RS | music | stimul. classical | 62.5 |  |  |
| 25 | Furnham et al. 1994 | 20 | | adults | within | RC | speech | TV drama | - |  |  |
| 26 | Johansson 1983 | 22 | 22 | children | between | RC | noise | continuous | 51 |  |  |
| 26 | Johansson 1983 | 22 | 22 | children | between | RC | noise | intermittent | 67.4 |  |  |
| 27 | Halin 2016 | 28 | | adults | within | RC | speech | native (easy) | 60 |  |  |
| 27 | Halin 2016 | 28 | | adults | within | RC | speech | native (diff) | 60 |  |  |
| 27 | Halin 2016 | 28 | | adults | within | RC | noise | traffic (easy) | 60 |  |  |
| 27 | Halin 2016 | 28 | | adults | within | RC | noise | traffic (diff) | 60 |  |  |
| 27 | Halin 2016 | 28 | | adults | within | RC | noise | aircraft (easy) | 60 |  |  |
| 27 | Halin 2016 | 28 | | adults | within | RC | noise | aircraft (diff) | 60 |  |  |
| 28 | Smith-Jacks. & Klein 2009 | 54 | | adults | within | PR | speech | native | 65 |  |  |
| 29 | Cauchard et al. 2012 | 30 | | adults | within | RC | music | instrumental | 65 |  |  |
| 29 | Cauchard et al. 2012 | 30 | | adults | within | RC | speech | native | 65 |  |  |
| 29 | Cauchard et al. 2012 | 30 | | adults | within | RS | music | instrumental | 65 |  |  |
| 29 | Cauchard et al. 2012 | 30 | | adults | within | RS | speech | native | 65 |  |  |
| 30 | Johansson et al. 2012 | 24 | | adults | within | RC | music | preferred | 65 |  |  |
| 30 | Johansson et al. 2012 | 24 | | adults | within | RC | music | non-preferred | 65 |  |  |
| 30 | Johansson et al. 2012 | 24 | | adults | within | RC | noise | cafe | 65 |  |  |
| 30 | Johansson et al. 2012 | 24 | | adults | within | RS | music | preferred | 65 |  |  |
| 30 | Johansson et al. 2012 | 24 | | adults | within | RS | music | non-preferred | 65 |  |  |
| 30 | Johansson et al. 2012 | 24 | | adults | within | RS | noise | cafe | 65 |  |  |
| 31 | Weinstein 1974 | 15 | 18 | adults | between | PR† | noise | teletype | 70 |  |  |
| 31 | Weinstein 1974 | 15 | 18 | adults | between | PR‡ | noise | teletype | 70 |  |  |
| 32 | Weinstein 1977 | 29 | | adults | within | PR† | speech | native | 68 |  |  |
| 32 | Weinstein 1977 | 29 | | adults | within | PR‡ | speech | native | 68 |  |  |
| 33 | Martin et al. 1988, Exp.1 | 36 | | adults | within | RC | speech | native | 82 |  |  |
| 33 | Martin et al. 1988, Exp.1 | 36 | | adults | within | RC | speech | random | 82 |  |  |
| 33 | Martin et al. 1988, Exp.1 | 36 | | adults | within | RC | music | instrumental | 82 |  |  |
| 33 | Martin et al. 1988, Exp.1 | 36 | | adults | within | RC | music | random tones | 82 |  |  |
| 33 | Martin et al. 1988, Exp.1 | 36 | | adults | within | RC | noise | white | 82 |  |  |
| 34 | Martin et al. 1988, Exp.2 | 36 | | adults | within | RC | music | instrumental | 82 |  |  |
| 34 | Martin et al. 1988, Exp.2 | 36 | | adults | within | RC | music | lyrical | 82 |  |  |
| 35 | Martin et al. 1988, Exp.4 | 48 | | adults | within | RC | noise | white | 82 |  |  |

Table B1 (continued)

*A Summary of the Studies and Their Effect Sizes That Were Included in the Meta-analysis*

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ID | Study | NC | NE | Sample | Design | DV | Sound | Sound type | dB(A) | g | var |
| 35 | Martin et al. 1988, Exp.4 | 48 | | adults | within | RC | speech | native | 82 |  |  |
| 35 | Martin et al. 1988, Exp.4 | 48 | | adults | within | RC | speech | foreign | 82 |  |  |
| 36 | Martin et al. 1988, Exp.5 | 48 | | adults | within | RC | noise | white | 82 |  |  |
| 36 | Martin et al. 1988, Exp.5 | 48 | | adults | within | RC | speech | non-word | 82 |  |  |
| 36 | Martin et al. 1988, Exp.5 | 48 | | adults | within | RC | speech | random words | 82 |  |  |
| 37 | Cool et al. 1994, Exp.2 | 9 | | children | within | RS | music | radio/ generic | - |  |  |
| 37 | Cool et al. 1994, Exp.2 | 9 | | children | within | RS | speech | movies | - |  |  |
| 37 | Cool et al. 1994, Exp.2 | 9 | | children | within | RC | music | radio/ generic | - |  |  |
| 37 | Cool et al. 1994, Exp.2 | 9 | | children | within | RC | speech | movies | - |  |  |
| 38 | Mitchell 1949 | 91 | | children | within | RTS | music | radio/ generic | - |  |  |
| 39 | Armstrong et al. 1991 | 33 | 30 | adults | between | RTS | speech | TV ads | - |  |  |
| 39 | Armstrong et al. 1991 | 33 | 32 | adults | between | RTS | speech | TV drama | - |  |  |
| 40 | Pool et al. 2000, Exp.1 | 30 | 30 | children | between | RC | speech | TV soap opera | 60 |  |  |
| 40 | Pool et al. 2000, Exp.1 | 30 | 30 | children | between | RC | music | TV music | 60 |  |  |
| 40 | Pool et al. 2000, Exp.1 | 30 | 30 | children | between | RS | speech | TV soap opera | 60 |  |  |
| 40 | Pool et al. 2000, Exp.1 | 30 | 30 | children | between | RS | music | TV music | 60 |  |  |
| 41 | Pool et al. 2000, Exp.2 | 48 | 24 | children | between | RC | speech | TV soap opera | 60 |  |  |
| 41 | Pool et al. 2000, Exp.2 | 48 | 24 | children | between | RC | music | TV music | 60 |  |  |
| 41 | Pool et al. 2000, Exp.2 | 48 | 48 | children | between | RS | speech | TV soap opera | 60 |  |  |
| 41 | Pool et al. 2000, Exp.2 | 48 | 48 | children | between | RS | music | TV music | 60 |  |  |
| 42 | Dockrell & Shield 2006 | 52 | 52 | children | between | RTS | noise | babble | 65 |  |  |
| 42 | Dockrell & Shield 2006 | 52 | 52 | children | between | RTS | noise | babble+environ. | 65 |  |  |
| 43 | Hyönä & Ekh. 2016, Exp.1 | 42 | | adults | within | RC | speech | native | 82.5 |  |  |
| 43 | Hyönä & Ekh. 2016, Exp.1 | 42 | | adults | within | RC | speech | foreign | 82.5 |  |  |
| 43 | Hyönä & Ekh. 2016, Exp.1 | 42 | | adults | within | RS | speech | native | 82.5 |  |  |
| 43 | Hyönä & Ekh. 2016, Exp.1 | 42 | | adults | within | RS | speech | foreign | 82.5 |  |  |
| 44 | Hyönä & Ekh. 2016, Exp.2 | 36 | | adults | within | RS | speech | scrambl.-differ. | 82.5 |  |  |
| 44 | Hyönä & Ekh. 2016, Exp.2 | 36 | | adults | within | RS | speech | scrambl.-same | 82.5 |  |  |
| 45 | Hyönä & Ekh. 2016, Exp.3 | 35 | | adults | within | RS | speech | native | 82.5 |  |  |
| 45 | Hyönä & Ekh. 2016, Exp.3 | 35 | | adults | within | RS | speech | scrambled | 82.5 |  |  |
| 46 | Hyönä & Ekh. 2016, Exp.4 | 36 | | adults | within | RS | speech | scrambled-sem. | 82.5 |  |  |
| 46 | Hyönä & Ekh. 2016, Exp.4 | 36 | | adults | within | RS | speech | scrm-syn+sem | 82.5 |  |  |
| 47 | Armstrong & Chung 2000 | 19 | 20 | adults | between | RC | speech | native | - |  |  |
| 48 | Madsen 1987, Exp.1 | 50 | 50 | adults | between | RC | music | various | 75 |  |  |
| 49 | Sörqvist 2010, Exp.1a | 23 | | children | within | RC | noise | aircraft | 57.5 |  |  |
| 50 | Sörqvist 2010, Exp.1b | 23 | | children | within | RC | speech | native | 57.5 |  |  |
| 51 | Sörqvist et al. 2010, Exp.1 | 24 | | adults | within | RC | speech | native | 65 |  |  |
| 52 | Sörqvist et al. 2010, Exp.2 | 42 | | adults | within | RC | speech | native | 65 |  |  |
| 53 | Halin et al. 2014 | 32 | | adults | within | RC | speech | native | 65 |  |  |
| 54 | Halin et al. 2014, Exp.1 | 31 | | adults | within | PR‡ | speech | native | 65 |  |  |
| 54 | Halin et al. 2014, Exp.1 | 31 | | adults | within | PR† | speech | native | 65 |  |  |
| 55 | Halin et al. 2014, Exp.2 | 29 | | adults | within | PR‡ | speech | native | 65 |  |  |
| 55 | Halin et al. 2014, Exp.2 | 29 | | adults | within | PR† | speech | native | 65 |  |  |
| 56 | Haapakangas et al. 2011 | 54 | | adults | within | PR‡ | speech | native | 48 |  |  |

Table B1 (continued)

*A Summary of the Studies and Their Effect Sizes That Were Included in the Meta-analysis*

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ID | Study | NC | NE | Sample | Design | DV | Sound | Sound type | dB(A) | g | var |
| 56 | Haapakangas et al. 2011 | 54 | | adults | within | PR† | speech | native | 48 |  |  |
| 56 | Haapakangas et al. 2011 | 54 | | adults | within | PRS | speech | native | 48 |  |  |
| 57 | Baker & Madell 1965 | 24 | | adults | within | RC | speech | native | - |  |  |
| 58 | Vasilev et al. n.d. | 40 | | adults | within | RC | noise | speech-spectr. | 60 |  |  |
| 58 | Vasilev et al. n.d. | 40 | | adults | within | RC | speech | foreign | 60 |  |  |
| 58 | Vasilev et al. n.d. | 40 | | adults | within | RC | speech | native | 60 |  |  |
| 58 | Vasilev et al. n.d. | 40 | | adults | within | RS | noise | speech-spectr. | 60 |  |  |
| 58 | Vasilev et al. n.d. | 40 | | adults | within | RS | speech | foreign | 60 |  |  |
| 58 | Vasilev et al. n.d. | 40 | | adults | within | RS | speech | native | 60 |  |  |

*Note*: NC: number of participants in the control (silence) condition. NE: number of participants in the experimental (sound) condition. RC: Reading comprehension. RS: reading speed. RTS: Reading test score. PR: Proofreading accuracy. ES: Effect size in Hedges’ g.

† Non-contextual errors (proofreading accuracy)

‡Contextual errors (proofreading accuracy)

References

Armstrong, G. B., Boiarsky, G. A., & Mares, M. L. (1991). Background television and reading performance. *Communications Monographs*, *58*(3), 235-253. doi:10.1080/03637759109376228

Avila, C., Furnham, A., & McClelland, A. (2011). The influence of distracting familiar vocal music on cognitive performance of introverts and extraverts. *Psychology of Music*, *40*(1), 84-93. doi:10.1177/0305735611422672

Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation*, *8*, 47-89. doi:10.1016/S0079-7421(08)60452-1

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology*, *8*(4), 485-493. doi:10.1037/0894-4105.8.4.485

Baker, R. W., & Madell, T. O. (1965). A continued investigation of susceptibility to distraction in academically underachieving and achieving male college students. Journal of Educational Psychology, 56(5), 254-258. doi:10.1037/h0022467

Beaman, C. P. (2005). Auditory distraction from low-intensity noise: A review of the consequences for learning and workplace environments. *Applied Cognitive Psychology*, *19*(8), 1041-1064. doi:10.1002/acp.1134

Borenstein, M. (2009). Effect sizes for continuous data. In H. M. Cooper, L. V. Hedges, & J. C. Valentine (Eds.), *The handbook of research synthesis and meta-analysis* (2nd ed., pp. 221-235). New York, USA: Russel Sage Foundation.

Cassel, E. E., & Dallenbach, K. M. (1918). The effect of auditory distraction upon the sensory reaction. *The American Journal of Psychology*, *29*(2), 129-143.

Cauchard, F., Cane, J. E., & Weger, U. W. (2012). Influence of background speech and music in interrupted reading: An eye‐tracking study. *Applied Cognitive Psychology*, *26*(3), 381-390. doi:10.1002/acp.1837

Clark, C., & Sörqvist, P. (2012). A 3 year update on the influence of noise on performance and behavior. *Noise and Health*, *14*(61), 292-296. doi:10.4103/1463-1741.104896

\* Cool, V. A., Yarbrough, D. B., Patton, J. E., Runde, R., & Keith, T. Z. (1994). Experimental effects of radio and television distractors on children's performance on mathematics and reading assignments. *The Journal of Experimental Education*, *62*(3), 181-194. doi:10.1080/00220973.1994.9943839

Dalton, B. H., & Behm, D. G. (2007). Effects of noise and music on human and task performance: A systematic review. *Occupational Ergonomics*, *7*(3), 143-152.

Daoussis, L., & McKelvie, S. J. (1986). Musical preferences and effects of music on a reading comprehension test for extraverts and introverts. *Perceptual and Motor Skills*, *62*(1), 283-289. doi:10.2466/pms.1986.62.1.283

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review*, *112*(4), 777-813. doi:10.1037/0033-295X.112.4.777

Etaugh, C., & Michals, D. (1975). Effects on reading comprehension of preferred music and frequency of studying to music. *Perceptual and Motor Skills*, *41*(2), 553-554. doi:10.2466/pms.1975.41.2.553

Etaugh, C., & Ptasnik, P. (1982). Effects of studying to music and post-study relaxation on reading comprehension. *Perceptual and Motor Skills*, *55*(1), 141-142. doi: 10.2466/pms.1982.55.1.141

Eysenck, H. (1967). *The biological basis of personality*. Springfield, IL: Thomas.

Fendrick, P. (1937). The influence of music distraction upon reading efficiency. *The Journal of Educational Research*, *31*(4), 264-271. doi:10.1080/00220671.1937.10880749

Fogelson, S. (1973). Music as a distractor on reading-test performance of eighth grade students. *Perceptual and Motor Skills*, *36*(3c), 1265-1266. doi:10.2466/pms.1973.36.3c.1265

Freeburne, C. M., & Fleischer, M. S. (1952). The effect of music distraction upon reading rate and comprehension. *Journal of Educational Psychology*, *43*(2), 101-109. doi:10.1037/h0054219.

Furnham, A., & Allass, K. (1999). The influence of musical distraction of varying complexity on the cognitive performance of extroverts and introverts. *European Journal of Personality*, *13*(1), 27-38. doi:10.1002/(SICI)1099-0984(199901/02)13:1<27::AID-PER318>3.0.CO;2-R

Furnham, A., & Bradley, A. (1997). Music while you work: The differential distraction of background music on the cognitive test performance of introverts and extraverts. Applied Cognitive Psychology, 11(5), 445-455. doi:10.1002/(SICI)1099-0720(199710)11:5<445::AID-ACP472>3.0.CO;2-R

Furnham, A., Gunter, B., & Peterson, E. (1994). Television distraction and the performance of introverts and extroverts. *Applied Cognitive Psychology*, *8*(7), 705-711. doi:10.1002/acp.2350080708

Furnham, A., & Stephenson, R. (2007). Musical distracters, personality type and cognitive performance in school children. *Psychology of Music*, *35*(3), 403-420. doi:10.1177/0305735607072653

Furnham, A., & Strbac, L. (2002). Music is as distracting as noise: The differential distraction of background music and noise on the cognitive test performance of introverts and extraverts. *Ergonomics*, *45*(3), 203-217. doi:10.1080/00140130210121932

Furnham, A., Trew, S., & Sneade, I. (1999). The distracting effects of vocal and instrumental music on the cognitive test performance of introverts and extraverts. Personality and Individual Differences, 27(2), 381-392. doi:10.1016/S0191-8869(98)00249-9

Gawron, V. J. (1984). Noise: Effect and aftereffect. *Ergonomics*, *27*(1), 5-18. doi:10.1080/00140138408963460

Haines, M. M., Stansfeld, S. A., Job, R. S., Berglund, B., & Head, J. (2001). Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children. *Psychological Medicine*, *31*(2), 265-277. doi:10.1017/S0033291701003282

Haka, M., Haapakangas, A., Keränen, J., Hakala, J., Keskinen, E., & Hongisto, V. (2009). Performance effects and subjective disturbance of speech in acoustically different office types– A laboratory experiment. *Indoor Air*, *19*(6), 454-467. doi:10.1111/j.1600-0668.2009.00608.x

Halin, N. (2016). Distracted while reading? Changing to a hard-to-read font shields against the effects of environmental noise and speech on text memory. *Frontiers in Psychology*, *7*, 1196. doi:10.3389/fpsyg.2016.01196

Halin, N., Marsh, J. E., Haga, A., Holmgren, M., & Sörqvist, P. (2014a). Effects of speech on proofreading: Can task-engagement manipulations shield against distraction? *Journal of Experimental Psychology: Applied*, *20*(1), 69-80. doi:10.1037/xap0000002

Halin, N., Marsh, J. E., Hellman, A., Hellström, I., & Sörqvist, P. (2014b). A shield against distraction. *Journal of Applied Research in Memory and Cognition*, *3*(1), 31-36. doi:10.1016/j.jarmac.2014.01.003

Hall, J. C. (1952). The effect of background music on the reading comprehension of 278 eighth and ninth grade students. *The Journal of Educational Research*, *45*(6), 451-458. doi: 10.1080/00220671.1952.10881962

Haapakangas, A., Kankkunen, E., Hongisto, V., Virjonen, P., Oliva, D., & Keskinen, E. (2011). Effects of five speech masking sounds on performance and acoustic satisfaction. Implications for open-plan offices. *Acta Acustica united with Acustica*, *97*(4), 641-655.

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

Henderson, M. T., Crews, A., & Barlow, J. (1945). A study of the effect of music distraction on reading efficiency. *Journal of Applied Psychology*, *29*(4), 313-317. doi:10.1037/h0056128

Hilliard, O. M., & Tolin, P. (1979). Effect of familiarity with background music on performance of simple and difficult reading comprehension tasks. *Perceptual and Motor Skills*, *49*(3), 713-714. doi:10.2466/pms.1979.49.3.713

Hughes, R. W. (2014). Auditory distraction: A duplex-mechanism account. *PsyCh Journal*, *3*(1), 30-41. doi:10.1002/pchj.44

Hughes, R., & Jones, D. M. (2001). The intrusiveness of sound: Laboratory findings and their implications for noise abatement. *Noise and Health*, *4*(13), 51-70.

Hughes, R. W., Vachon, F., & Jones, D. M. (2005). Auditory attentional capture during serial recall: Violations at encoding of an algorithm-based neural model? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(4), 736-749. doi:10.1037/0278-7393.31.4.736.

Hughes, R. W., Vachon, F., & Jones, D. M. (2007). Disruption of short-term memory by changing and deviant sounds: Support for a duplex-mechanism account of auditory distraction. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(6), 1050-1061. doi:10.1037/0278-7393.33.6.1050.

Hygge, S., Evans, G. W., & Bullinger, M. (2002). A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren. *Psychological Science*, *13*(5), 469-474. doi:10.1111/1467-9280.00483

\* Hyönä, J., & Ekholm, M. (2016). Background speech effects on sentence processing during reading: An eye movement study. *PLoS One*, *11*(3), e0152133.

Jäger, L. A., Engelmann, F., & Vasishth, S. (2017). Similarity-based interference in sentence comprehension: Literature review and Bayesian meta-analysis. *Journal of Memory and Language*, *94*, 316-339. doi:10.1016/j.jml.2017.01.004

Jahncke, H., Hygge, S., Halin, N., Green, A. M., & Dimberg, K. (2011). Open-plan office noise: Cognitive performance and restoration. *Journal of Environmental Psychology*, *31*(4), 373-382. doi:10.1016/j.jenvp.2011.07.002

Johansson, C. R. (1983). Effects of low intensity, continuous and intermittent noise on mental performance and writing pressure of children with different intelligence and personality characteristics. *Ergonomics*, *26*(3), 275-288. doi:10.1080/00140138308963341

Johansson, R., Holmqvist, K., Mossberg, F., & Lindgren, M. (2012). Eye movements and reading comprehension while listening to preferred and non-preferred study music. *Psychology of Music*, *40*(3), 339-356. doi:10.1177/0305735610387777

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*(2), 369-381. doi:10.1037/0278-7393.19.2.369

Jones, D., Madden, C., & Miles, C. (1992). Privileged access by irrelevant speech to short-term memory: The role of changing state. *The Quarterly Journal of Experimental Psychology*, *44*(4), 645-669. doi:10.1080/14640749208401304

Jones, D. M., Miles, C., & Page, J. (1990). Disruption of proofreading by irrelevant speech: Effects of attention, arousal or memory? *Applied Cognitive Psychology*, *4*(2), 89-108. doi:10.1002/acp.2350040203

Kallinen, K. (2002). Reading news from a pocket computer in a distracting environment: effects of the tempo of background music. *Computers in Human Behavior*, *18*(5), 537-551. doi:10.1016/S0747-5632(02)00005-5

Kämpfe, J., Sedlmeier, P., & Renkewitz, F. (2010). The impact of background music on adult listeners: A meta-analysis. *Psychology of Music*, *39*(4), 424-448. doi:10.1177/0305735610376261

Kiger, D. M. (1989). Effects of music information load on a reading comprehension task. *Perceptual and Motor Skills*, *69*(2), 531-534. doi:10.2466/pms.1989.69.2.531

Klatte, M., Bergström, K., & Lachmann, T. (2013). Does noise affect learning? A short review on noise effects on cognitive performance in children. *Frontiers in Psychology*, 4, 578. doi:10.3389/fpsyg.2013.00578

Lajeunesse, M. J. (2013). Recovering missing or partial data from studies: A survey of conversions and imputations for meta-analysis. In J. Koricheva, J. Gurevitch, & K. Mengersen (Eds.), *The handbook of meta-analysis in ecology and evolution* (pp. 195–206). Princeton: Princeton University Press.

Landström, U., Söderberg, L., Kjellberg, A., & Nordström, B. (2002). Annoyance and performance effects of nearby speech. *Acta Acustica United with Acustica*, *88*(4), 549-553.

Ljung, R., Sorqvist, P., & Hygge, S. (2009). Effects of road traffic noise and irrelevant speech on children's reading and mathematical performance. *Noise and Health*, *11*(45), 194-198.

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*(3), 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*(1), 23-38. doi:10.1016/j.cognition.2008.08.003

Marsh, J. E., & Jones, D. M. (2010). Cross-modal distraction by background speech: What role for meaning? *Noise and Health*, *12*(49), 210-216.

\* 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*(4), 382-398. doi:10.1016/0749-596X(88)90063-0

Miller, L. K., & Schyb, M. (1989). Facilitation and interference by background music. *Journal of Music Therapy*, *26*(1), 42-54. doi:10.1093/jmt/26.1.42

Miller, L. R. (1947). Some effetcs of radio-listening on the efficiency of reading type study acitivities. *The Journal of Educational Psychology*, *38*(2), 105-118. doi:10.1037/h0062228

Mitchell, A. H. (1949). The effect of radio programs on silent reading achievement of ninety-one sixth grade students. *The Journal of Educational Research*, *42*(6), 460-470. doi:10.1080/00220671.1949.10881709

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7), e1000097. doi:10.1371/journal.pmed.1000097

Morgan, J. B. (1917). The Effect of Sound Distraction upon Memory. *The American Journal of Psychology*, *28*(2), 191–208.

Nakagawa, S., Noble, D. W., Senior, A. M., & Lagisz, M. (2017). Meta-evaluation of meta-analysis: Ten appraisal questions for biologists*. BMC Biology*, *15*(1), 18. doi:10.1186/s12915-017-0357-7

Papanikolaou, M., Skenteris, N., & Piperakis, S. M. (2015). Effect of external classroom noise on schoolchildren’s reading and mathematics performance: Correlation of noise levels and gender. *International Journal of Adolescent Medicine and Health*, *27*(1), 25-29. doi:10.1515/ijamh-2014-0006

Perham, N., & Currie, H. (2014). Does listening to preferred music improve reading comprehension performance?. *Applied Cognitive Psychology*, *28*(2), 279-284. doi:10.1002/acp.2994

Ravaja, N., & Kallinen, K. (2004). Emotional effects of startling background music during reading news reports: The moderating influence of dispositional BIS and BAS sensitivities. *Scandinavian Journal of Psychology*, *45*(3), 231-238. doi:10.1111/j.1467-9450.2004.00399.x

Rohatgi, A. (2015). digitizeR: Tool to extract numerical data from images of plots, maps, etc.. *R package version 1.0*. Retrieved from http://github.com/ankitrohatgi/digitizeR

Salamé, P., & Baddeley, A. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behavior*, *21*(2), 150-164. doi:10.1016/S0022-5371(82)90521-7

Salamé, P., & Baddeley, A. (1987). Noise, unattended speech and short-term memory. *Ergonomics*, *30*(8), 1185-1194. doi:10.1080/00140138708966007

Salamé, P., & Baddeley, A. (1989). Effects of background music on phonological short-term memory. The Quarterly Journal of Experimental Psychology, 41(1), 107-122. doi:10.1080/14640748908402355

Shield, B. M., & Dockrell, J. E. (2003). The effects of noise on children at school: A review. *Building Acoustics*, *10*(2), 97-116. doi:10.1260/135101003768965960

Smith-Jackson, T. L., & Klein, K. W. (2009). Open-plan offices: Task performance and mental workload. *Journal of Environmental Psychology*, *29*(2), 279-289. doi:10.1016/j.jenvp.2008.09.002

Sörqvist, P. (2010). High working memory capacity attenuates the deviation effect but not the changing-state effect: Further support for the duplex-mechanism account of auditory distraction. *Memory & Cognition*, *38*(5), 651-658. doi:10.3758/MC.38.5.651

Sörqvist, P., Halin, N., & Hygge, S. (2010). Individual differences in susceptibility to the effects of speech on reading comprehension. *Applied Cognitive Psychology*, *24*(1), 67-76. doi:10.1002/acp.1543

Sörqvist, P., Ljungberg, J. K., & Ljung, R. (2010). A sub-process view of working memory capacity: Evidence from effects of speech on prose memory. *Memory*, *18*(3), 310-326. doi: 10.1080/09658211003601530

Sörqvist, P., & Marsh, J. E. (2015). How concentration shields against distraction. *Current Directions in Psychological Science*, *24*(4), 267-272. doi:10.1177/0963721415577356

Stansfeld, S. A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Öhrström, E., ... & RANCH Study Team. (2005). Aircraft and road traffic noise and children's cognition and health: A cross-national study. *The Lancet*, *365*(9475), 1942-1949. doi:10.1016/S0140-6736(05)66660-3

Sterne, J. A., Sutton, A. J., Ioannidis, J. P., Terrin, N., Jones, D. R., Lau, J., ... & Tetzlaff, J. (2011). Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. *BMJ*, *343*, d4002. doi:10.1136/bmj.d4002

Sutton, A. J., & Abrams, K. R. (2001). Bayesian methods in meta-analysis and evidence synthesis. *Statistical Methods in Medical Research*, *10*(4), 277-303. doi:10.1177/096228020101000404

Sutton, A. J., Abrams, K. R., Jones, D. R., Jones, D. R., Sheldon, T. A., & Song, F. (2000). *Methods for meta-analysis in medical research*. Chichester, UK: John Wiley & Sons.

Szalma, J. L., & Hancock, P. A. (2011). Noise effects on human performance: A meta-analytic synthesis. *Psychological Bulletin*, *137*(4), 682-707. doi:10.1037/a0023987

Thompson, W. F., Schellenberg, E. G., & Letnic, A. K. (2012). Fast and loud background music disrupts reading comprehension. *Psychology of Music*, *40*(6), 700-708. doi: 10.1177/0305735611400173

Tucker, A., & Bushman, B. J. (1991). Effects of rock and roll music on mathematical, verbal, and reading comprehension performance. *Perceptual and Motor Skills*, *72*(3), 942-942. doi:10.2466/pms.1991.72.3.942

Vachon, F., Hughes, R. W., & Jones, D. M. (2012). Broken expectations: Violation of expectancies, not novelty, captures auditory attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(1), 164 -177. doi:10.1037/a0025054

Vasishth, S. (2015). *A meta-analysis of relative clause processing in Mandarin Chinese using bias modelling* (Doctoral dissertation, The University of Sheffield).

Vasishth, S., Chen, Z., Li, Q., & Guo, G. (2013). Processing Chinese relative clauses: Evidence for the subject-relative advantage. *PLoS One*, *8*(10), e77006. doi:10.1371/journal.pone.0077006

Vasilev, M. R., Liversedge, S. P., Rowan, D., Kirkby, J. A., & Angele, B. (2017). Reading is disrupted by intelligible background speech: Evidence from eye-tracking. *Unpublished manuscript*.

Veitch, J. A. (1990). Office noise and illumination effects on reading comprehension. *Journal of Environmental Psychology,* *10*(3), 209-217. doi:10.1016/S0272-4944(05)80096-9

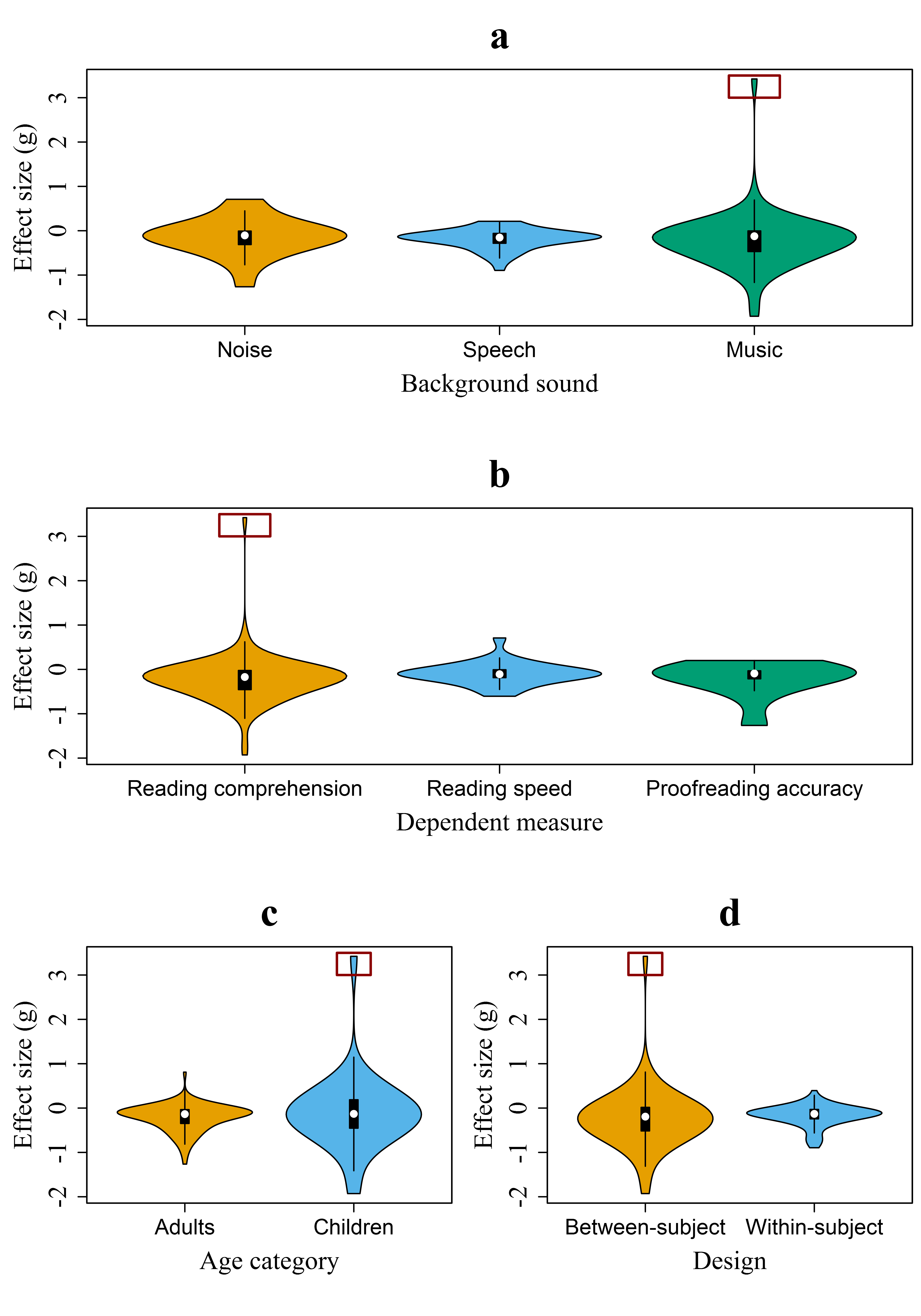
Venetjoki, N., Kaarlela-Tuomaala, A., Keskinen, E., & Hongisto, V. (2006). The effect of speech and speech intelligibility on task performance. *Ergonomics*, *49*(11), 1068-1091. doi:10.1080/00140130600679142

Weinstein, N. D. (1977). Noise and intellectual performance: A confirmation and extension. *Journal of Applied Psychology*, *62*(1), 104-107. doi:10.1037/0021-9010.62.1.104

Ylias, G., & Heaven, P. C. (2003). The influence of distraction on reading comprehension: A Big Five analysis. *Personality and Individual Differences*, *34*(6), 1069-1079. doi:10.1016/S0191-8869(02)00096-X

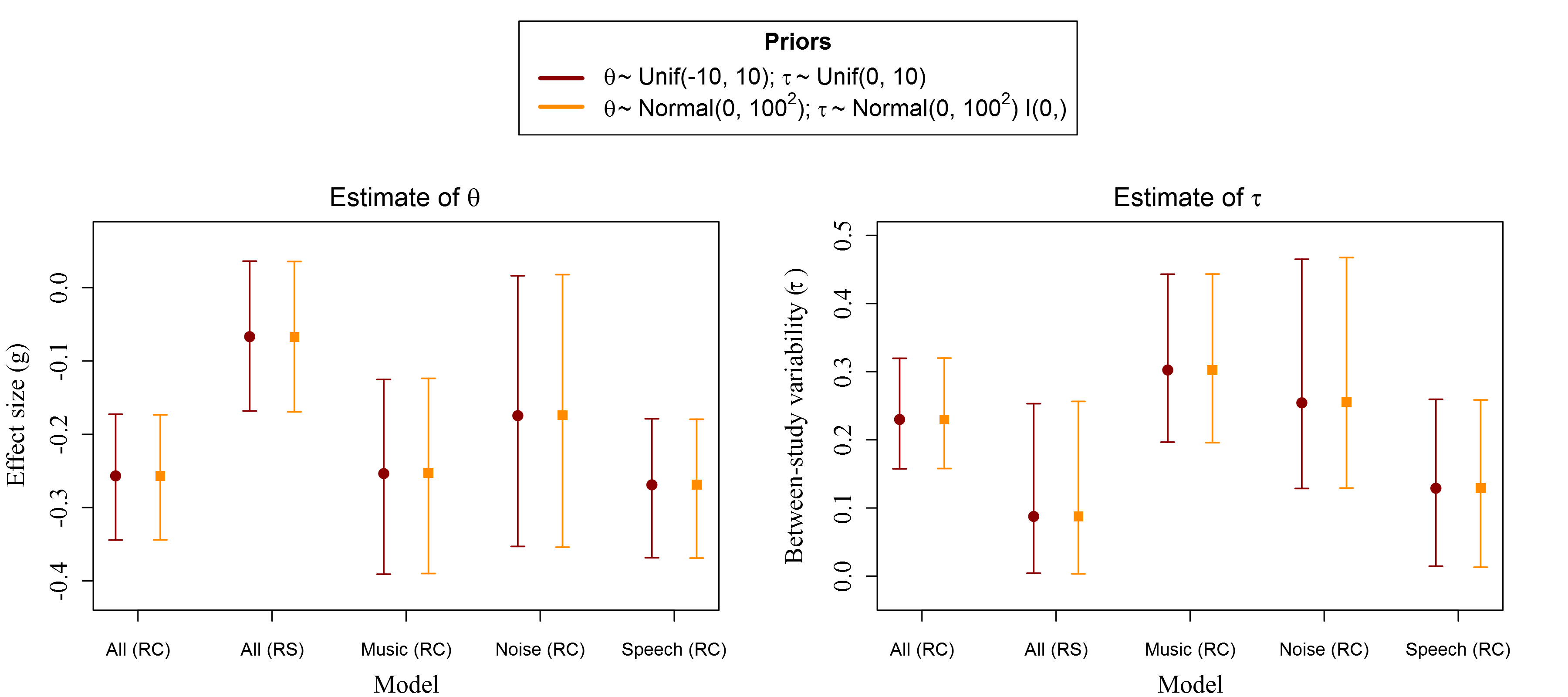
Supplemental Material

**Visualization of Effect Sizes**



*Figure Sx*. Box plots and probability densities of the effect sizes included in the meta-analysis. Breakdown shown by: background sound type (panel **a**), dependent measure (panel **b**), age of participants (panel **c**), and study design (panel **d**). Red rectangle shows the one effect size that was excluded as an outlier.

**Prior Sensitivity Analysis**



*Figure Sx*. Sensitivity analysis with different priors on the θ and τ parameters for the main meta-analysis results. Uniform priors (dark red) were used in the analysis reported in the main paper. The results show that using diffuse normal priors did not change the main results reported in the paper. All: all studies. RC: reading comprehension. RS: reading speed.

1. One eligible (unpublished) study by the first author was also included. [↑](#footnote-ref-1)