Title: Distraction distance and disturbance by noise – An analysis of 21 open-plan offices

Comment [HV1]: En pysty tekemään tarkistusta kunnolla, koska kuvat puuttuu. Ensi kerralla voisitko panna niin ,että kuvat ovat mukana dokumentissa. Ne saa kyllä laittaa JASAankin dokumentin sisään ja kuvatekstit kuvan alle. Se vain helpottaa review prosessia. Kuvien laitto erikseen on taittajan työn takia ja sen voi tehdä erikseen mutta kässäriä ei kannata näin rikottaa.

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Running title: Disturbance by noise in open-plan offices

Abstract

Noise complaints are common in open-plan offices. Previous research suggests that these problems may be related to high intelligibility of speech. Distraction distance, which is based on the Speech Transmission Index, can be used to objectively describe the room acoustic quality of open-plan offices. However, the relation between distraction distance and perceived noise has not been established in field studies. The aim of this study was to synthesize evidence from separate studies covering 21 workplaces (~~N=~~88~~8~~3 respondents) and a wide range of room acoustic conditions. The data included both surveys and room acoustic measurements (ISO 3382-3). Distraction distance and the spatial decay rate of speech were examined as predictors of perceived disturbance by colleagues' speech and by office noise in general. The data were analyzed with individual participant data meta-analysis. The results suggest that distraction distance, but not the spatial decay rate, predicts disturbance by speech and by office noise in general. The odds ratios ranging from 1.10 to 1.15 indicated that every one meter increase in distraction distance predicted 10-15 percent increase in the odds of perceiving high disturbance by noise. The results support the role of room acoustic design in the attainment of good working conditions in open-plan offices.

Keywords: Speech Transmission Index; open-plan offices; noise; distraction distance

I Introduction

Since the introduction of open-plan offices, their acoustic conditions have been a source of dissatisfaction for workers (e.g., Becker, Gield, Gaylin & Sayer, 1983; Bodin Danielsson & Bodin, 2009; Boyce, 1974; Brookes & Kaplan, 1972; Haapakangas, Helenius, Keskinen & Hongisto, 2008; Kaarlela-Tuomaala, Helenius, Keskinen & Hongisto, 2009; Nemecek & Grandjean, 1973; Pejtersen, Allermann, Kristensen & Poulsen, 2006; Pierrette, Parizet, Chevret & Chatillon, 2015). The complaints include both distracting noise ~~but also~~ and insufficient speech privacy. The acoustic problems are not restricted to annoyance as office noise may also negatively contribute to employee well-being (Haapakangas et al., 2008; Lee, Lee, Jeon, Zhang & Kang, 2016; Klitzman & Stellman, 1989; Pierrette et al., 2015), job satisfaction (Sundstrom, Town, Rice, Osborn & Brill, 1994) and work performance (Becker et al., 1983; Kaarlela-Tuomaala et al., 2009; Lamb & Kwok, 2016).

According to several field studies, coworkers' speech is the most annoying noise source in open-plan offices (e.g., Banbury & Berry, 2005; Hongisto, Haapakangas, Varjo, Helenius & Koskela, 2016; Kaarlela-Tuomaala et al., 2009; Pierrette et al., 2015). Accumulating evidence from experimental psychology show that irrelevant speech, i.e. background speech that is not useful to the performed task, has detrimental effects on cognitive performance (e.g., Haka et al., 2009; Hongisto, 2005; Martin, Wogalter & Forlano, 1988; Salamé & Baddeley, 1987; Schlittmeier, Hellbrück, Thaden & Vorländer, 2008). Importantly, the negative effects on performance are not caused by the sound pressure level (SPL) of speech but by increasing speech intelligibility (Colle, 1980; Ellermeier & Hellbrück, 1998; Hongisto, 2005; Hongisto, Varjo, Leppämäki, Oliva & Hyönä, 2016; Schlittmeier et al., 2008). Therefore, the room acoustic design of open-plan offices should aim at reducing the spatial ~~propagation~~ decay rate of speech level and intelligibility of background speech (Hongisto, Keränen & Larm, 2004; Virjonen, Keränen & Hongisto, 2009).

According to the hypothetical model by Hongisto (2005), the detrimental effect of irrelevant speech on performance begins to decrease when the intelligibility of speech declines below Speech Transmission Index (STI) 0.50. A few laboratory studies have tested the effect of STI concluding that the STI of irrelevant speech predicts ~~particularly~~ specifically speech privacy (Lee & Jeon, 2014) and subjective perceptions of the acoustic environment (Haapakangas et al., 2011; Haapakangas, Hongisto, Hyönä, Kokko & Keränen, 2014; Haka et al., 2009; Hongisto et al., 2016b) ~~but also~~as well as cognitive performance (Haapakangas et al. 2014; Haka et al., 2009; Jahncke, Hongisto & Virjonen, 2013; Keus van de Poll, Ljung, Odelius & Sörqvist, 2014; Schlittmeier & Liebl, 2015).

In open-plan offices, the reduction of STI requires the simultaneous use of absorption, screens and masking sound (Hongisto et al., 2004; Keränen, Hongisto, Oliva & Hakala, 2012). However, the effects of room acoustic elements on STI are small at short distances (Haapakangas et al., 2014; Keränen et al., 2012). Adjacent workstations tend to remain within distraction distance (r_D, ISO 3382-3) which defines the distance from speech source at which STI falls below 0.50, i.e. within which speech is assumed to be distracting. The only laboratory experiment taking this limitation into account (Haapakangas et al., 2014) ~~,~~concluded that, while the room acoustic design had an effect on performance and acoustic comfort, its benefits were limited because STI could not be reduced enough between neighboring workstations.~~smaller than expected~~ ~~(Haapakangas et al., 2014).~~

In the light ~~with~~ of the evidence from psychological laboratory experiments, it would be important to show that room acoustic design predicts perceived noise disturbance in real offices. However, field studies including both acoustic surveys and relevant room acoustic measurements are rare. ~~because of the novelty of the ISO 3382-3 standard. This standard defines single number quantities that can be used to describe the room acoustic quality of an~~

Comment [HV2]: Tämä on huono ilmaisu, ei me oletettu paperissa etukäteen mitään suuria vaan oli STI mittausten perusteella etukäteen varmuudella tiedossa, että vaimennustekijäin vaikutus ei näy lähityöpisteessä, vain kaukana. Mistähän tämä "expected" on tullut tai mihin viittaa? Korjataan myöhemmin.

Comment [HA3]: olet oikeassa. Tässä on ollut tarkoitus sanoa että vaikutus on vähäisempi kuin se mitä aiempien "akateemisempien" tutkimusten perusteella voisi olettaa (koska niissä ei ole huomioitu sitä että lähietäisyydellä STI:tä ei saa tarpeeksi pieneksi). Muokkasin.

open-plan office. In addition to r_D, these parameters include $D_{2,S}$ and $L_{A,S,4m}$ which are related to room absorption **(Figure 1).**

Hongisto and colleagues (Helenius & Hongisto, 2004; Hongisto, 2008; Hongisto, Haapakangas, Helenius, Keränen & Oliva, 2012; Hongisto et al., 2012b; Hongisto et al. 2016a) have reported several case studies in which room acoustic improvements were conducted in open-plan offices. These studies provide support for the association between r_D and acoustic satisfaction. In addition, a field experiment by Seddigh, Berntson, Jönsson, Danielson and Westerlund (2015) showed that adding room absorption affects room acoustic parameters ($D_{2,S}$, $L_{A,S,4m}$ and radius of comfort, r_C) and may decreases acoustic disturbance and cognitive stress. Seddigh et al. (2015) focused on the attenuation of noise only and did not report r_D nor other parameters related to speech intelligibility.

However, individual case studies suffer from small samples, compare a limited number of acoustic conditions and are prone to confounding factors. A cross-sectional study by Newsham, Veitch and Charles (2008) combined data from nine buildings and 779 respondents but found no evidence of a significant relation did not find evidence of a relation between acoustic satisfaction and room acoustic quality, as described by Speech Intelligibility Index (, SII). This result may be explained by their measurement method which only considered the SII between two neighboring workstations. However, the presentprevailingcurrent internationally adopted approach (ISO 3382-3) is based on the principle that the measurements should reflect the room acoustic quality of the whole open-plan office instead of neighboring workstations (Virjonen et al., 2009; Keränen & Hongisto, 2013, Keränen et al., 2012).

The ISO 3382-3 standard defines single number quantities that can be used to describe the room acoustic quality of an open-plan office. In addition to r_D, the standard includes three other parameters. The spatial decay rate of speech ($D_{2,S}$) describes how much the level of A-weighted speech reduces when the distance to the speaker is doubled. The SPL of speech at a 4-meter distance from the speaker ($L_{A,S,4m}$) and the average background noise level ($L_{p,A,B}$) are also measured. A large value of $D_{2,S}$ and a small value of $L_{A,S,4m}$ indicate that speech is efficiently attenuated. A small value of r_D indicates high speech privacy, i.e. low speech intelligibility, and thus, less distraction by background speech.

Of the ISO 3382-3 quantities, r_D is most directly related to speech intelligibility because it measures the combined effect of room absorption, room volume and geometry screens between workstations and background sound. , room volume and geometry between workstations, $D_{2,S}$ and $L_{A,S,4m}$ mainly relateddependent on to the amount of room absorption, room volume and geometry and screens. but tThey do not take into account the background noise level which is important for speech intelligibility (Hongisto, 2005). As Because rD takes all important factors into account, r_D takes all of these factors into account, it can be considered asis the most important room acoustic single outcome variable of the ISO 3382-3 method.

The quantity takes all above-mentioned factors into account. The lower is the value of rD, the smaller area will be disturbed by a single speaker in the office. Low value of Because rD takes all important factors into account, r_D is the most important single outcome variable of ISO 3382-3 method. However, the consideration use of r_D alone maybe misleading is dangerous as already explained by (Virjonen et al., (2009). The most simple and low-cost way cheapest way to decrease achieve small value of r_D r_D isis -to use high increase the background noise level ($L_{p,A,B}$). For example, the use of a sound masking level of $L_{p,A,B}$ = 50 dB with no sound absorbers in the room would easily decrease r_D below 5 meters due to highly reverberant and masked nearby speech.distraction distances less than 5 meter, which is a recommended value of class A offices according to a Finnish standard (RIL 243-3-2008),

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Comment [HA4]: geometry screens kuulostaa oudolta. Puuttuu jokin sana? geometry yksinään kuulostaa liian yleiseltä, tarkoitatko room geometry?

Comment [HA5]: geometry screens kuulostaa oudolta. Puuttuu jokin sana? geometry yksinään kuulostaa liian yleiseltä, tarkoitatko room geometry?

Comment [HA6]: Ei voi olla kahta and-sanaa näin lähekkäin. Tarkoitatko ”room volume, room geometry and screens”?

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~~can be easily achieved by using a sound masking level of $L_{p,A,B}$ = 50 dB in the whole and leaving all sound absorbers away so that nearby speech becomes very strongly reverberant and masked.~~ Such -acoustic conditions would likely be experienced as very disturbing and detrimental for communication~~a high levels of masking can be unbearably disturbing as well as the resulting poor communication intelligibility~~. On the other hand, the use of $L_{A,S,4m}$ and $D_{2,S}$ without r_D is not recommended either. In certain conditions, an increment of $D_{2,S}$ and decrement of $L_{A,S,4m}$ will increase r_D instead of reducing it (Virjonen et al. 2007; Keränen et al., 2012). When the masking level is low, increasing room absorption will reduce reverberation which, in turn, increases the value of STI. ~~To avoid unsuccessful designs~~Thus, t~~described above, t~~he parallel consideration ~~use~~ of all four room acoustic variables (r_D, $D_{2,S}$, $L_{A,S,4m}$ ~~and $D_{2,S}$~~ and $L_{p,A,B}$) is necessary~~safer than using r_D only~~. Small r_D is obtained in conditions where $L_{A,S,4m}$ is low and $D_{2,S}$ and $L_{p,A,B}$ are high.

~~The use of $L_{A,S,4m}$ and $D_{2,S}$ without rD is not recommended because Increasing absorptionIncrement of $D_{2,S}$ and decrement of $L_{A,S,4m}$ maywill, in certain conditions, increase r_D instead of reducing it (Virjonen et al. 2007; Keränen et al., 2012). This can happen when the masking level is low: increment of e.g. room absorption will reduce reverberation which again increases the value of STI. However, $D_{2,S}$ and $L_{A,S,4m}$ wereare correlated with r_D in a field study of 16 offices (Virjonen et al., 2009). Therefore, both $D_{2,S}$ and $L_{A,S,4m}$ and could predict disturbance by office noise due to this connection. In practice, r_D depends largely on $L_{p,A,B}$ and higher $L_{p,A,B}$ could, thus, be associated with lower disturbance by noise in open-plan offices. However, if background noise is perceived as annoying in itself, an increase in perceived disturbance would be expected.~~

Comment [HV7]: tämä toistaa edell. kappaletta

Comment [HA8]: onko lauserakenne oikein eli riippuuko jälkikaiunta todella taustaäänitasosta? Olisiko oikeampi toisin päin: Increasing room absorption reduces reverberation which, in turn, increases the value of STI if the masking level is low.

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Comment [HV9]: tämä toistaa edell. kappaletta

More evidence is needed of the association between room acoustic ~~quantities~~ variables and subjective acoustic conditions. To address this gap in the literature, this paper examines whether the ~~parameters~~room acoustic ~~parameters~~ quantities –of ISO 3382-3 ~~distraction distance (r_D) and the spatial decay rate of speech ($D_{2,S}$)~~ predict perceived disturbance by noise in a sample of 21 open-plan offices. ~~This study combines data from separate case studies conducted at 21 workplaces between 2002 and 2014. As the studies were conducted independently of each other, they involve differences in study designs, sample sizes, workplace characteristics and data gathering time. Thus, the evidence is synthesized using individual participant data meta-analysis. This analytic approach takes into account the hierarchical data structure in which the participants are clustered within workplaces that may have their own effect on perceived noise due to differences between the original study designs and other workplace characteristics (Debray et al., 2015).~~

The hypothesis of this study is that increase in distraction distance (r_D) predicts increase in the perceived disturbance by noise. The associations between perceived disturbance and the other room acoustic variables are also examined. However, specific hypotheses are not stated for $L_{A,S,4m}$, $D_{2,S}$ and $L_{p,A,B}$ because the existing research on their association with perceived noise in open-plan offices is scarce and they are not independent from the main variable r_D. It is possible that these parameters do not alone predict perceived noise disturbance because they measure more restricted aspects of room acoustic conditions. ~~Experimental studies suggest that reducing the SPL of speech is not in itself sufficient to reduce the negative effects of background speech (Schlittmeier et al., 2008) and the evidence on the role of room absorption in more realistic settings is scarce and contradictory (Haapakangas et al., 2014; Seddigh et al., 2015). Increasing absorption may, in certain conditions, increase r_D instead of reducing it (Keränen et al., 2012). However, $D_{2,S}$ and $L_{A,S,4m}$ are correlated with r_D (Virjonen et al., 2009) and could predict disturbance by office noise due to this connection. In practice,~~

Comment [HV10]: TAVOITE on aivan **liian pitkä**, siitä onneksi voi repiä palasia metodeihin, kuten alla kuvattu.

Comment [HV11]: tämä kuuluu menetelmiin, epäolennainen tavoitteissa.

Comment [HV12]: Tämä ei kuulu tavoitteeseen vaan menetelmiin. Siirrä se sinne, koska tavoitteen arvo hononee kun heti selitellään sitä, miksi aineisto on heikkoa. Kukaan muukaan ei tee niin, sitä paitsi tavoitteessa ei saa olla uusia asioita saatikka viitteitä, jotka eivät ole esiintyneet ennen tavoitteen asettamista ja jotka eivät edes liity itse tutkimukseen, yksinomaan menetelmiin. Hypoteeseissä voi olla viitteitä, mutta sekin on epätoivottavaa, koska ne olisi oltava ennen tavoitetta jo kuvattu.

Comment [HV13]: 1.Lause ei ole totta. Jos vaimentaa tarpeeksi, STI kyllä pienenee nollaan. 2. Lause ei selkeytä mitään: en ymmärrä siitä mitään joten ei muutkaan ymmärrä. Sitä paitsi room absorption sanan käyttö yksin on virhe. Se tehtiin TOTI paperissa mutta tässä introssa ei saa puristaa absorption, seinäkkeiden ja huonetilavuuden/geometrian yhteisvaikutuksia yhteen sanaan "room absorption"

r_D depends largely on $L_{p,A,B}$ and higher $L_{p,A,B}$ could, thus, be associated with lower disturbance by noise in open-plan offices. However, if background noise is perceived as annoying in itself, an increase in perceived disturbance would be expected However, $D_{2,S}$ and $L_{A,S,4m}$ are correlated with r_D (Virjonen et al., 2009) and could predict disturbance by office noise due to this connection. Similarly, higher $L_{p,A,B}$ could be associated with lower disturbance by noise because $L_{p,A,B}$ is an important determinant of r_D.

Comment [HV14]: siirsin ennen tavoitetta, koska pilaa merkittävästi tavoitteen ytimekkyyttä tässä kohtaa

The earlier research on the role of the spatial decay rate of speech ($D_{2,S}$) is scarce and contradictory (Haapakangas et al. 2014; Seddigh et al., 2015). As experimental studies suggest that the SPL of speech is not associated with perceived noise (Colle, 1980; Ellermeier & Hellbrück, 1988), it is assumed that $D_{2,S}$ does not predict the disturbance by office noise.

II Methods

A Included workplacesstudies

This study is based on combined data from separate case studies conducted at 21 workplaces Case studies conducted at 21 workplaces by Finnish Institute of Occupational Health between 2002 and 2014 were included in the meta-analysis. The sample excludes call centers and similar workplaces with constant babble. Open-plan offices were defined as workspaces of six or more occupants. After excluding individuals in private and shared offices, data from 888883 respondents in open-plan offices was available. Most of the data was gathered in different research projects but some data originated from acoustic evaluations requested by workplaces experiencing noise complaints. In the latter case, the organizations gave a consent for the use of data in this study.

The data originate from different research designs described in **Table I**. All studies included a questionnaire survey and room acoustic measurements. In 15 studies with repeated measures data (i.e., before-after designs involving a change in the office environment), the first measurement conducted in an open-plan office was included in the meta-analysis. In one case (Workplace ~~12~~13 in **Table II**), the second measurement was used because the first survey was retrospective, i.e. the respondents were evaluating an office in which they no longer worked.

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Some of the open-plan offices ~~included features of~~were activity-based offices (Appel-Meulenbroek, Groenen & Janssen, 2011) in which ~~, that is,~~ workers were able to use alternative workspaces, such as ~~the offices included additional~~ silent rooms, in addition to the open-plan workspace ~~that could be used for concentration and speech privacy when needed~~. All respondents had, however, assigned workstations in an open-plan office.

A summary of the workplaces is presented in **Table II** including ~~basic data on key variables as well as~~ background information about the organizations, respondents and original studies. Some studies include~~d~~ data from several workplaces and, thus, the data ~~were~~ are grouped on the basis of workplaces rather than original studies. A few of the workplaces belong~~ed~~ to the same organizations but a~~we~~re considered separate cases in this study because of obvious differences in location, physical office features, room acoustic quality, work tasks or management. Most of the data has not been published previously.

B Room acoustic measurements

Room acoustic properties of open-plan office areas were measured according to the ISO 3382-3 standard. The standard did not exist when most of the offices were investigated but the measurement method was developed during the early years of this study, published first by Hongisto, Virjonen and Keränen (2007) and later in detail by Virjonen et al. (2009).

The basic idea of the method is to measure the level and intelligibility of normal-effort speech in the workstation area at various distances from the speech source at one workstation (**Figure 2**). The speech was produced using an omnidirectional loudspeaker. ~~Three~~ Four

Comment [HA15]: Reviewer: Line 139: In general, please describe the number of sampling points in the measurement

Comment [HA16]: muista lisätä taustaäänitaso sekä se miten Lps4m määritettiin.

~~quantities~~ ~~parameters~~room acoustic variables were derived. The distraction distance, r_D (m), describes the distance where the Speech Transmission Index, STI, falls below 0.50 (**Figure 1b**). The STI is an objective descriptor of speech intelligibility which can have values from 0 to 1. The spatial decay rate of speech, $D_{2,S}$ (dB), describes how much the level of A-weighted speech reduces when the distance to the speaker is doubled (**Figure 1a**). The third quantity, $L_{A,S,4m}$, measures the speech level at 4-meter distance ~~but is not considered in this meta-analysis~~. The ~~fourth parameter was the~~ mean background noise of the office, $L_{p,A,B}$ (dB), ~~which~~ excludes the activity noise but include~~volve~~s the steady-state sounds of the building, mainly caused by ventilation ~~noise~~ or a sound masking system.

~~A small value of r_D indicates high speech privacy, i.e. low speech intelligibility, and thus, less distraction by background speech. A large value of $D_{2,S}$ indicates that speech is efficiently attenuated when the distance to the speaker increases.~~ The ~~accuracy~~ measurement uncertainty of the ISO 3382-3 ~~measurement results~~ method has not been published in the standard. The experience and unpublished data of the authors suggest that the estimated uncertainty (68% confidence interval) is ±1 dB for $D_{2,S}$ and ±1.5 m for r_D based on repeated measurements in the same office. The measurement results for each workplace are shown in **Table III**.

C Variables

The primary predictor variables of this study w~~ere~~are the room acoustic parameters of ISO 3382-3 standard: *distraction distance* (~~,~~ r_D~~,~~), ~~*measured in meters, and*~~ *the spatial decay rate of speech* (~~,~~ $D_{2,S}$), *the SPL of speech at 4 meters* ($L_{p,A,S,4m}$) and *the background noise level* ($L_{p,A,B}$). The latter three are measured in A-weighted decibels while r_D is expressed in meters. *Age* and *gender* were also included in the models. Age was divided into three categories: under 31 years old, 31 to 50 years old and over 50 years old.

Comment [HA17]: mittalukujen tulkinta (eli onko pieni vai suuri luku hyvä) on siirretty introon. Introssa on myös keltaisella maalatut määritelmät joten mieti, otetaanko pois tästä tai lyhennetäänkö. STI on kuitenkin hyvä selittää koska sitä ei ole introssa. Samoin taustaäänitason sisältöä ei ole kerrottu introssa. Tähän kohtaan voisi sopia niiden kuvien selitys, sitä kritisoitiin vaikeaksi (ks reviewerin kommentti alla) ja introssa on muutenkin jo paljon asiaa. Siis kuvien 1a ja 1b selitykset.

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Comment [HA18]: Reviewer: Line 145: It might just be something specific to me, but I found it a little hard to read the figure with the definition in this sentence. Maybe a little bit more explanation to help readers understand the D_2,s in the figure is a particular example?

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Comment [HA19]: lisäykset uusista muuttujista

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The subjective outcome variables were are *disturbance by noise in general* and *disturbance by background speech*. The original surveys were much wider and their content varied between workplaces (for examples, see Kaarlela-Tuomaala et al., 2009 and Hongisto et al., 2016). which were coded into two categories (0 = low disturbance, 1 = high disturbance). The outcome variables original items were originally rated on a 5-point scale (1 = not at all, 2 = only slightly, 3 = somewhat, 4 = quite a lot, 5 = very much) but were re-coded into two categories (0 = low disturbance, 1 = high disturbance). The -'low of which the highest two values comprise the 'high disturbance' category comprises the responses from 1 to 3 while the highest two values were coded as 'high disturbance'. The original items were strongly correlated (r=.77, p<0.001). The phrasing of the questions had minor differences between workplaces. Disturbance by noise in general assessed how much the respondent had been disturbed by noise at his or /her workstation recently. Disturbance by background speech was assessed with a similar question focusing on the distraction caused by different noise speech sources. Two to three sources of background speech that were relevant to the particular office were rated at each workplace. The speech sources included , such as speech from other desks in the open-plan office and speech from shared facilities, but other sources that were present at a particular office were also included (e.g., conversations at a coffee machine or speech from private office rooms). Due to this variation between surveys, aA variable for disturbance caused by background speech was coded as the highest rating given by the respondent to any of the speech sources because this was assumed to measure the most relevant source of distraction for a particular respondent.. This variable was used for forming the binary outcome. For approximately 82% of the respondents, speech from other workstations in the open-plan office was the most distracting source of background speech. The proportion of respondents in the 'high disturbance' category at each workplace is shown in **Table III**.

D Statistical analyses

As the original studies were conducted independently from each other, methodological differences exist in study designs, sample sizes, workplace characteristics and data gathering. Thus, the evidence is synthesized using individual participant data meta-analysis. This analytic approach takes into account the hierarchical data structure in which the participants are clustered within workplaces that may have their own effect on the perceived noise due to differences between the original study designs and other workplace characteristics (Debray et al., 2015).

One-stage meta-analysis of individual participant data (Debray et al., 2015) was conducted using two-level logistic regression with respondents (level 1) nested in workplaces (level 2). Room acoustic predictors were level 2 variables, that is, their values did not vary within workplaces (**Table II**). Initially, we considered a mixed model which included a random intercept for workplace, a random slope for the room acoustic predictor and fixed effects for other predictors. The random components were included to account for heterogeneity across workplaces, that is, disturbance by noise (random intercept) and the effect of room acoustic predictors on disturbance (random slope) were allowed to vary between workplaces. However, the initial models indicated low heterogeneity in the effects of the room acoustic predictors~~r_D and $D_{2,S}$~~. As these ~~room acoustic~~ predictors were workplace-level variables, the random slope probably ~~does~~ did not account for any extra variation in addition to what ~~is~~ was already covered by the random intercept for workplace. Thus, the analyses are reported using a random intercept model including fixed effects for the room acoustic predictor, age and gender.

Separate models were fitted for each room acoustic predictor (r_D, $D_{2,S}$, $L_{p,A,S,4\,m}$ and $L_{p,A,B}$) and for both binary outcome variables (noise in general and background speech). As **Table III** shows, the proportion of respondents in the high disturbance category is lower in the

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activity-based offices (range 6-30 %) compared with the traditional open-plan offices (range 17-71 %). It may be that the activity-based features reduce perceived disturbance by noise in the office because workers may also use more quiet workspaces. Inclusion of these offices in the complete sample may, therefore, underestimate noise disturbance and its association to the room acoustic predictors. Thus, s~~S~~eparate models were also fitted for the complete sample (k=21, n=8~~80~~75) and a sample excluding open-plan offices with an activity-based concept (k=17, n=662~~7~~). ~~because~~The samples exclude eight respondents due to missing data on some of the questionnaire items. ~~activity-based features were assumed to possibly decrease disturbance by office distractions.~~ For the models for disturbance by background speech, one workplace with ten respondents was also excluded due to missing data on this outcome (Workplace 2 in **Table II**).

First, the effects of the acoustic predictor variables, age and gender on the outcome variables were modelled separately from each other. At the next stage, age and gender were separately added to the models of each room acoustic predictor. In the final models, the effects of the room acoustic predictors were adjusted for both age and gender. As the variation in the values of $L_{p,\mathrm{A,S,4\,m}}$ was large compared with the values of age and gender, $L_{p,\mathrm{A,S,4\,m}}$ was mean-centered prior to the analyses. The rescaled values, thus, indicated how many decibels a given workplace was above or below the sample mean.

All models were fitted using maximum likelihood with Laplace approximation. OR's~~dds ratios (OR)~~ with 95% confidence intervals (CI) are reported. The data were analyzed with R (version 3.2.2, R Core Team, 2015) using the lme4 package (Bates, Maechler, Bolker & Walker, 2015).

III Results

A Preliminary analyses

Table IV shows the descriptive results for the samples used in the analyses. Of the 875 participants, approximately 38% belong to the 'high disturbance' category indicating that, overall, respondents were more likely to perceive low disturbance by noise in general and by background speech. The corresponding odds for high disturbance are 0.61. ~~However, t~~The proportion of individuals perceiving high disturbance by noise in general varies considerably between workplaces (6.4% to 70.8%, odds 0.07 to 2.4). The variation is slightly larger for disturbance by background speech (5.6% to 80%, odds 0.06 to 4).

Figure 3 shows the percentage of respondents in the 'high disturbance' category at each workplace in relation to the room acoustic ~~predictors~~parameter. Correlations between the room acoustic p~~redictor~~arameters and the outcome variables based on the aggregate data are shown in **Table V**. The correlation coefficients and the scatter plots in **Figure ?** suggest that r_D, $L_{p,A,S,4\,m}$ and $L_{p,A,B}$ are associated with both outcome variables whereas $D_{2,S}$ is not. The scatter plot for $L_{p,A,S,4\,m}$ shows one outlier (WP 12 in **Table III**). Excluding this outlier decreases the linear correlation between $L_{p,A,S,4m}$ and disturbance by noise in the complete sample (r = 0.36) and erases it in the sample excluding activity-based offices (r = 0.17). The subjective outcome variables are highly correlated, suggesting that the disturbance by background speech largely explains the perception of disturbing noise in general (**Table V**). Of the acoustic predictors, r_D is correlated with $L_{p,A,S,4m}$ and particularly $L_{p,A,B}$, as would be expected. $D_{2,S}$ is associated with $L_{p,A,S,4m}$ but not with r_D nor $L_{p,A,B}$.

Separate unadjusted models of each predictor indicate that r_D is associated with both outcome variables in both samples (OR's 1.09 to 1.14). $L_{p,A,S,4\,m}$ and $L_{p,A,B}$ are associated with both outcomes in the complete sample (OR's 1.20-1.27 and 0.91, respectively). In the sample excluding activity-based offices, odd ratios for $L_{p,A,S,4\,m}$ and $L_{p,A,B}$ are smaller and mostly

Comment [HV20]: mistä tämä tulee, epäselvä`?

Comment [HA21]: yleensä oddseista ei puhuta artikkeleissa koska oletetaan että ihmiset tietävät mikä on odds ja odds ratio. Mutta ajattelin laskea sen tähän havainnollistamaan odds ja odds ratio -asiaa. Asia voidaan myös kokonaan jättää pois. Se viittaa edelliseen lauseeseen ("corresponding"). Eli korkean häiritsevyyden odds koko aineistossa on 38 % / 62 % = 0.61. Odds ratiohan (käsittääkseni) viittaa siihen, kuinka paljon odds muuttuu.

Comment [HV22]: However on tässä kohtaa turha, koska kerrot vasta faktoista, jotka aiheuttavat tulokset.

Comment [HV23]:

Comment [HV24]: mihin viittaa, epäselvä

Comment [HA25]: kuten edellä, eli 0.064/0.936 = 0.07 jne. Näitä ei ruveta kirjoittamaan auki vaan jätetään ennemmin kokonaan pois.

Comment [HV26]: mihin viittaa, epäselvä

Comment [HV27]: ei korrelaatioanalyysissa kannata puhua predictoreista vielä. quantity, parameter, variable predictor. Luettavuus paranee kun on vähän rooleja fysikaalisella muuttujalla.

Predictor yksin on huono.

Pari:
acoustic predictor variable
subjective outcome variable
toimisi parhaiten ja olisi ymmärrettävin.

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non-significant. $D_{2,S}$ is not associated with the outcome variables in any of the unadjusted models. The unadjusted models for age show a nearly significant association with disturbance by noise in general, suggesting that the odds of high disturbance might be increased among over 50 years old compared with under 31 years old (OR 1.58, 95% CI 0.97 to 2.58, p = .07). This tendency does not appear for disturbance by background speech nor when activity-based offices are excluded. Gender is not associated with noise disturbance in any of the preliminary models.

Most of the significant associations between the room acoustic predictors and the outcome variables are not attenuated when age and gender are separately added to the model. An exception to this is the association between $L_{p,A,S,4m}$ and disturbance by noise in general (OR 0.93, 95% CI 0.87 to 1.00, p = 0.06) which is no longer significant in the sample excluding activity-based offices when the effect of age is controlled. The associations between $D_{2,S}$ and the outcome variables remain nonsignificant after separately adjusting for age and gender.

B Final models

The results of the final models for both samples are shown in **Table VI**. Overall, excluding activity-based offices produces slightly smaller estimates for the association between the room acoustic predictors and the outcome variables, probably because of the smaller sample size.

As the ORs show, r_D predicts disturbance by both noise sources in both samples when its effect is adjusted for both age and gender. Every one meter increase in r_D predicts an approximately 13% increase in the odds of perceiving high disturbance by noise in general and 14 % increase in the odds of perceiving high disturbance by background speech. These percentual increases in the odds per one meter are small. However, a one meter change is not practically relevant as it is likely within the measurement error for r_D. It is more meaningful

Comment [HV28]: Table VI. En ymmärrä, mihin tarvitaan rivejä Age 31-50, Age>51, Gender, kun niissä ei ole lihavointeja (ei merkitseviä tuloksia, voisi jättää pois koko asian) ja niistä ei moni lukija muutenkaan ymmärrä mitään ja kolmanneksi miksi ne edes on valittu, kun on paljon muitakin demografisia tekijöitä, joihin adjustmentin voisi tehdä. Minkä teorian mukaan ikä ja sukupuoli olisivat tärkeitä? miksei vaikka ammattiasema ennemmin tai koulutustaso tai työkokemus yrityksessä?

Sitä paitsi ikä ja sukupuoli näyttäisivät olevan vasta Table VI final modelin puolella. Preliminary analysis koskee kai vain taulukkoa V, jossa on korrelaatioita-.

Comment [HA29]: ikä ja sukupuoli ovat perusasioita jotka konrolloidaan tällaisissa malleissa. Se ei liit siihen ajatellaanko niillä olevan vaikutusta vai ei. Pyritään lisäämään mallin selittämän varianssin osuutta. Olisi ollut hyvä kontrolloida enemmän tekijöitä (esim. koulutustaso, esimiesasema) mutta niistä ei ole kattavaa dataa.
Taulukossa VI kerrotaan myös ikä ja sukupuoli koska ne kuuluvat malliin. Siellä on myös jotain lähes merkitseviä tuloksia joten siksikin kiinnostava.

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to consider a larger unit, such as a 5-meter difference which can be calculated by raising the original OR to the fifth power. A five-meter increase in r_D predicts an approximately 84% increase in the odds of high disturbance by noise in general and 92.5% increase in the odds of perceiving high disturbance by background speech.

The models for $L_{p,A,S,4m}$ indicate that for every one decibel increase the odds of high disturbance by noise in general increase by 20% and the odds of perceiving high disturbance by background speech increase by 27%. However, the ORs are smaller (1.09 and 1.11, respectively) and nonsignificant in the sample excluding activity-based offices. Removing the outlier (WP 12, **Figure** ??) decreases ORs slightly in both samples but the association remains statistically significant in the complete sample.

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$L_{p,A,B}$ is associated with the both outcome variables in the complete sample. A one decibel increase in $L_{p,A,B}$ predicts a small decrease (9%) in the odds of perceiving high disturbance both by noise in general and by background speech. As with $L_{p,A,S,4\,m}$, the ORs become smaller and nonsignificant when activity-based offices are excluded.

$D_{2,S}$ does not predict disturbance by noise in general or by background speech in any of the models. Age and gender are neither significant predictors in any of the final models although the nonsignificant tendency towards an effect of age persists for disturbance by noise in general in the complete sample.

The estimated random intercepts describing heterogeneity between workplaces are shown for the main variable r_D in **Figures** ??. The variance between workplaces is low as the 95% confidence intervals include the value ‘1’ in most cases. The models of the other room acoustic predictors had similarly low heterogeneity.~~**A Preliminary analyses**~~

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~~**Table III** shows the descriptive results for the samples used in the analyses. Of the 880 participants, 37.5% belonged to the ‘high disturbance’ category indicating that, overall,~~

respondents were more likely to perceive low disturbance by noise in general. The corresponding odds for high disturbance are 0.6. However, the proportion of individuals perceiving high disturbance by noise in general varied considerably between workplaces (0% to 70.8%, odds 0 to 2.4).

Figure 3 shows the percentage of respondents in the 'high disturbance' category for each workplace in relation to the room acoustic predictors. The scatter plots appear to support the assumptions that the disturbance by noise in general is associated with r_D but not with $D_{2,S}$.

Separate unadjusted models of each predictor indicated that r_D was associated with both outcome variables in both samples (OR's 1.09 to 1.15) whereas $D_{2,S}$ was not (OR's 0.96 to 1.06, $p > .05$). There was a tendency towards an effect of age on the disturbance by noise in general. This trend suggests that the odds of high disturbance were increased among over 50 years old compared with under 31 years old (OR 1.53, 95% CI 0.94 to 2.49, $p = .09$). In addition, men tended to perceive less disturbance by background speech than women although this trend was not significant (OR 0.76, 95% CI 0.55 to 1.05, $p = .09$). The tendencies involving age and gender were weaker in the sample excluding the activity-based offices.

The associations between r_D and the outcome variables were not attenuated when age and gender were separately added to the model. The effect of $D_{2,S}$ on the outcomes remained nonsignificant after separately adjusting for age and gender.

B Final model

The results of the final models are shown in **Table IV**. As the ORs show, r_D predicted disturbance by noise when its effect was adjusted for age and gender. Every one meter increase in r_D predicted an approximately 15% increase in the odds of perceiving high disturbance by noise in general and by background speech. This effect is small but it corresponds to the doubled odds of high disturbance for a five-meter increase in r_D (1.15^5=2.01). Excluding open-plan offices with activity-based features produced slightly smaller estimates for the association between r_D and disturbance by noise but did not change the pattern of results.

The estimated random intercepts describing heterogeneity between workplaces are shown in **Figures 4** and 5. Overall, the variance between workplaces was low as the 95% confidence intervals included the value '1' in most cases.

As hypothesized, $D_{2,S}$ did not predict disturbance by noise in general or by background speech (**Table IV**). The tendencies for age and gender persisted in the final model but were not significant in any of the analyses.

IV Discussion

The aim of this study was to synthesize data from 21 workplaces to examine whether distraction distance (r_D) and other room acoustic variables of the ISO 3382-3 standard are associated withquality predicts perceived disturbance by noise in open-plan offices. Two room acoustic predictors were investigated: distraction distance (r_D) which reflects speech intelligibility as defined by the Speech Transmission Index and the spatial decay rate of speech ($D_{2,S}$) which reflects the spatial attenuation of sound in the space. Overall, tThe hypothesies that r_D, but not $D_{2,S}$, would predict be associated with disturbance by noise wasere supported by the results. The speech level at a 4 meter distance ($L_{p,A,S,4m}$) and the average background noise level ($L_{p,A,B}$) were also associated with disturbance by noise in some of the models. The spatial decay rate of speech ($D_{2,S}$) did not predict disturbance by noise.

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A Speech intelligibility, distraction distance and perceived noise

The results are compatible with the literature describing background speech as a central noise problem in open-plan offices (e.g., Banbury & Berry, 2005; Pierrette et al., 2015; Schlittmeier & Liebl, 2015; Haapakangas et al., 2008). The ~~is was shown by the strong correlation between~~ disturbance ~~caused~~ by noise in general correlated strongly with disturbance by background speech ~~and noise in general~~which suggests that the general perception of disturbing noise was largely explained by distracting background speech. The associations between a ~~models~~particular room acoustic predictor and perceived disturbance were also similar for both outcomes ~~were also similar~~. However, the ~~odds ratios for background speech were slightly smaller than those obtained for noise in general. The~~ models predicting disturbance by noise in general are probably more reliable because this outcome variable is more consistent with the original measurements and may also cover subsidiary sources of noise, such as office equipment and people moving in the building. The variable for background speech was constructed from ~~a variety~~ heterogeneous~~of~~ questions which likely resulted in some loss of accuracy.

The results show that perceived noise disturbance is related to speech intelligibility and its room acoustic descriptor, r_D, in open-plan offices. ~~To date, the strongest evidence for the use of STI as a predictor of noise effects has come from laboratory experiments examining the role of speech intelligibility (e.g., Haapakangas et al., 2014; Haka et al., 2009; Hongisto et al. 2016; Jahncke et al. 2013). However, the extent to which these findings can be generalized to real workplaces has been uncertain, particularly as most studies have not considered the practical limitations involved in room acoustic design (for an exception, see Haapakangas et al., 2014). A few case studies have provided evidence for an association between~~ ~~r_D and perceived noise (Helenius & Hongisto, 2004; Hongisto, 2008; Hongisto et al. 2012a; Hongisto et al. 2016a) but studies at individual workplaces are prone to confounding and do~~

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not establish a general relation between room acoustic conditions and perceived noise. The present study extends this area of research by providing a unique synthesis of data covering a large range of room acoustic conditions and different workplaces. The results are in line with the above-mentioned findings from both laboratory and field studies.

The results support the use of r_D as a descriptor of room acoustic quality of open-plan offices. Depending on the sample and the specific outcome, the increase in the odds of high disturbance by noise ranged from 10 9 to 154 percent per one meter increase in r_D. These figures equal 54 to 93 percent increase in the doubled odds of high disturbance per five5 to 7.3 meter increase in r_D which is a more suitable unit for evaluating differences in room acoustic design. The association between r_D and noise disturbance was significant in both samples. For $L_{p,A,S,4m}$ and $L_{p,A,B}$ the results differ between the samples which could be due to the change in sample size or any bias created by activity-based offices in the complete sample. The inclusion of the activity-based offices in the complete sample does not seem to create any obvious bias in the models of r_D because the range of r_D is wide in the activity-based offices (2.5 to 14 meters) and, thus, the inclusion of these offices does not weight the r_D-disturbance relation in a particular direction. The inclusion of a few open-plan offices with activity-based features did not attenuate the observed results even though the perceived noise appeared lower in these offices (**Table II**). The role of speech intelligibility is further supported by the finding that higher background sound level ($L_{p,A,B}$) $D_{2,S}$, which measures the attenuation of speech level but not speech intelligibility, did not predict perceived disturbance.was associated with lower disturbance by noise in the complete sample. This suggests that the background sound is not perceived as a noise source in open-plan offices but is beneficial because it decreases speech intelligibility.

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To date, the strongest evidence for the use of STI as a predictor of noise effects has come from laboratory experiments examining the role of speech intelligibility (e.g., Haapakangas et al., 2014; Haka et al., 2009; Hongisto et al. 2016; Jahncke et al. 2013). However, the extent to which these findings can be generalized to real workplaces has been uncertain, particularly as most studies have not considered the practical limitations involved in room acoustic design (for an exception, see Haapakangas et al., 2014). A previous cross-sectional study by Newsham et al. (2008) did not find an association between room acoustic measurements of speech intelligibility and acoustic satisfaction. The difference to the present results is likely explained by their measurement method which only considered speech intelligibility between neighboring workstations. The variation of speech intelligibility is smaller at short distances and the STI tends to be near 0.50 between neighboring workstations even in the best room acoustic conditions (Keränen et al., 2012). The ISO 3382-3 method used in the present study seems more appropriate for determining the room acoustic quality because it considers the whole office space. The present study suggests that background speech originating from workstations further away is relevant to the perception of disturbing noise even though room acoustic design cannot eliminate potential distraction from neighboring workstations (Haapakangas et al., 2014; Keränen et al., 2012). Decreasing noise disturbance between neighboring workstations would require extreme measures which would likely impair normal communication.

B The room acoustic variables related to the attenuation of noise

The SPL of speech at a 4-meter distance ($L_{A,S,4m}$) was also associated with both outcome variables in the complete sample. The smaller sample size may explain why significant associations were not observed when activity-based offices were excluded. An alternative possibility is that the activity-based offices biased the complete sample because these offices had both low $L_{A,S,4m}$ (44.6-47.8 dB) and low noise disturbance (**Table ??, Figure 3**). This association may be a coincidence or it may represent a real relation between $L_{A,S,4m}$ and perceived noise disturbance. However, when the activity-based offices and one outlier were

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removed from the analysis, the association between $L_{A,S,4m}$ and noise disturbance disappeared. This suggests that the results of the complete sample may be biased and should be viewed with caution. $L_{A,S,4m}$ is also more susceptible to measurement error than r_D and $D_{2,S}$ because $L_{A,S,4m}$ is only measured at one location.

The spatial decay rate of speech level ($D_{2,S}$) did not predict noise disturbance in any of the models. Both $L_{A,S,4m}$ and $D_{2,S}$ are related to the attenuation of speech level: $L_{A,S,4m}$ indicates how well speech is attenuated at 4 meters after it leaves the workstation whereas $D_{2,S}$ indicates the efficiency of attenuation in relation to increasing distance. The lack of clear evidence for $L_{A,S,4m}$ and $D_{2,S}$ is compatible with laboratory studies showing that the decrease in speech level (Hongisto et al. 2016; Schlittmeier et al., 2008) or increase in absorption (Haapakangas et al., 2014??) do not alone decrease the detrimental effects of background speech if speech intelligibility is not simultaneously decreased. In contrast, a field experiment by Seddigh et al. (2015) found an association between changes in room absorption and perceived noise disturbance. However, Seddigh et al. (2015) did not report background sound level nor r_D. Thus, the possibility that their results are explained by changes in speech intelligibility, rather than only attenuation, cannot be excluded.

Nevertheless, the present results do not imply that $L_{A,S,4m}$ and $D_{2,S}$ are not important for the room acoustic quality. It is rather suggested that $L_{A,S,4m}$ and $D_{2,S}$ alone may not predict perceived noise and, thus, they should not be considered without taking the background sound level and STI into account. In practice, both efficient attenuation of speech and high background sound level ($L_{p,A,B}$) are needed to reduce STI below 0.50 at shorter distances. $L_{A,S,4m}$ and $D_{2,S}$ correlate with r_D (Virjonen et al. 2009) although in the present study r_D was mainly determined by $L_{p,A,B}$.

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It is also possible that the radius of comfort (r_c) used by Seddigh et al. (2015) is a better predictor for disturbance by noise than $L_{A,S,4m}$ or $D_{2,S}$ alone. The radius of comfort has not been defined in any standard. It is defined as the distance at which the A-weighted level of speech meets 48 dB (Seddigh et al., 2015). The formula for calculating r_c takes into account both $D_{2,S}$ and $L_{A,S,4m}$. The association between the radius of comfort and noise disturbance could be examined in future studies.

However, a field experiment by Seddigh et al. (2015) observed changes in noise disturbance following changes in room absorption.

C Strengths and limitations

It is possible that the radius of comfort (r_c) used by Seddigh et al. (2015) is a better predictor for disturbance by noise than $D_{2,S}$. The radius of comfort has not been defined in any standard. It was defined as the distance at which the A-weighted level of speech falls below 48 dB by Seddigh et al. (2015). Unlike $D_{2,S}$, this quantity also takes into account the speech level at a 4-meter distance which varies at least from 41 dB (Hongisto et al., 2016b) to 57 dB (Keränen & Hongisto, 2013) between open-plan offices. The association between the radius of comfort and noise disturbance could be examined in future studies.

The present study provides a unique synthesis of data associating objective room acoustic measurements with subjective noise disturbance in open-plan offices. The strength of the data is that it covers 21 workplaces and a large range of room acoustic conditions. To date, the assumptions on the role of r_D have been based on laboratory experiments (e.g., Haka et al., 2009; Jahncke, Hongisto & Virjonen, 2013; Schlittmeier & Liebl, 2015) and case studies at single workplaces (Helenius & Hongisto, 2004; Hongisto, 2008; Hongisto et al. 2012a; Hongisto et al. 2016a), both of which have weaknesses in terms of the generalizability of their conclusions. The present study is in line with the above-mentioned laboratory and field studies and extends this are of research to more general and realistic conditions.

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~~The determination of the acoustic quality of open-plan offices has shifted from measurements between neighboring workstations (Bradley & Wang, 2001; Hongisto et al., 2004) to the consideration of the whole office space (ISO 3382-3; Virjonen et al., 2009). The latter approach is further supported by the present data. Even though neighboring workstations are within distraction distance forming a potential source of distraction (Haapakangas et al., 2014; Keränen et al., 2012), the present study suggests that background speech originating from workstations further away is relevant to the perception of disturbing noise. The development of room acoustic measurement methods may also explain the difference between the present results and those obtained by Newsham et al. (2008) who measured speech intelligibility between nearby workstations and did not find an association between room acoustic measurements and acoustic satisfaction.~~

This study includes several uncertainties and limitations that may have implications for the interpretation of the results. First, the studied room acoustic predictors are indirect indicators of noise because they measure the acoustic properties of a room ignoring the noise levels from the actual activity. In order to more accurately establish the relation between ~~rD~~ a room acoustic variable and noise disturbance, the sound exposure should be constant across individuals and offices. Such conditions have been tested in laboratory settings, leading to evidence of the effects of STI~~this relation~~ (e.g., Haapakangas et al., 2014; Jahncke et al., 2013) but similar control cannot be achieved in field studies. The sound exposure at an office is likely affected by the nature of work, isolation from areas with other functions (e.g., breakout spaces) and the presence and mobility of workers. In addition, the shape, size and space-efficiency of an office affect the number of workstations ~~within the radius of~~inside distraction distance. Despite the exclusion of workplaces with constant babble, these factors could not be controlled and, thus, the obtained estimates inevitably contain some inaccuracy. However, it should be noted that including measurements of the overall office sound levels in

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the meta-analysis would not have adequately reflected the noise exposure. The measured office noise levels ha~~s~~ve not been associated with the perceptions of noise in previous field studies (e.g., Kaarlela-Tuomaala et al., 2009; Nemecek & Grandjean, 1973; Pierrette et al., 2015). As noted by Kaarlela-Tuomaala et al. (2009), the overall sound level does not differentiate between the useful and irrelevant sounds of which only the latter are perceived as noise. It would be difficult to develop an objective measure that would differentiate unwanted distracting speech from speech that is relevant for the respondent (e.g., one's conversation with others).

In addition, the room acoustic predictors were determined at the office level as they are also defined in the ISO 3382-3 standard. The room acoustic measurements may in themselves involve some measurement error. Particularly $L_{A,S,4m}$ is susceptible to measurement error because it is only determined at one location, unlike r_D and $D_{2,S}$. More importantly, the acoustic conditions at individual workstations may ~~have~~ deviate~~d~~ from the overall measurement. Workers may experience different levels of noise in the same office because of small physical differences between workstations (e.g., proximity to a wall or other individual reflecting surface) and because of variation in their position in relation to noise sources. For example, a worker located in a corner would only be exposed to one quarter of the radius of distraction experienced by a person in the middle of a large office. However, the results of the present study are supported by the fact that the association between STI and noise effects has been observed in laboratory studies in which these factors have been controlled (e.g., Haka et al., 2009; Jahncke et al., 2013).

~~The aforementioned limitations imply that the present study does not exclude the possibility that the quantity $D_{2,S}$ is associated with disturbance by noise in open-plan offices. Although the results clearly do not support such an assumption, a reliable test of the role of $D_{2,S}$ would require laboratory conditions in which the noise exposure and other sources of confounding~~

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are controlled. Assuming background speech as the primary source of noise, previous research does not support the assumption that the attenuation of speech level decreases noise effects if speech intelligibility is not decreased (Haapakangas et al., 2014; Hongisto et al. 2016; Schlittmeier et al., 2008). However, a field experiment by Seddigh et al. (2015) observed changes in noise disturbance following changes in room absorption. It is possible that the radius of comfort (r_c) used by Seddigh et al. (2015) is a better predictor for disturbance by noise than $D_{2,S}$. The radius of comfort has not been defined in any standard. It was defined as the distance at which the A-weighted level of speech falls below 48 dB by Seddigh et al. (2015). Unlike $D_{2,S}$, this quantity also takes into account the speech level at a 4-meter distance which varies at least from 41 dB (Hongisto et al., 2016b) to 57 dB (Keränen & Hongisto, 2013) between open-plan offices. The association between the radius of comfort and noise disturbance could be examined in future studies.

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Finally, the reliability of the statistical estimates may have been affected by differences among workplaces and the sample size, particularly the number of clusters (i.e. workplaces). The meta-analysis included data from different research contexts and designs. Call centers were excluded to homogenize the sample because of a particular acoustic environment (i.e. constant babble) and common problems related to working conditions and employee well-being (Deery, Iverson & Walsh, 2002). However, there have likely been other differences between workplaces which could not be controlled in this study. While individual participant data meta-analysis takes the workplace-level heterogeneity into account, the number of workplaces was fairly small in relation to what is generally recommended for multilevel models (e.g., McNeish & Stapleton, 2016). Thus, the low heterogeneity observed in the models may not accurately reflect differences between workplaces due to the small number of clusters. Ideally, this study should be replicated with a larger number of workplaces and a uniform design for data gathering. The applicability of the present conclusions to call centers should also be separately examined in future research as the sample did not include such workplaces.

D Practical implications

As a practical implication, the results support the use of r_D as an indicator of the room acoustic quality of open-plan offices. It can be measured to evaluate the acoustic conditions according to the ISO 3382-3 standard. The acoustic conditions of an open-plan office can be improved by decreasing r_D which requires the simultaneous use of screens, absorption in the room and furniture surfaces and masking sound (Haapakangas et al., 2014; Keränen et al., 2012; Keränen & Hongisto, 2013). The decrease in r_D should be distinct (~~over~~ at least 5 meters) in order to impact perceived noise. As office noise is also associated with worker well-being (Haapakangas et al., 2008; Lee et al., 2016; Pierrette et al., 2015) and performance (Schlittmeier & Liebl, 2015), it is possible that decreasing the disturbance of office noise might attenuate some of these problems. The association between distraction distance and employee well-being and performance would be an important topic for future research on open-plan offices.

E Conclusions

~~To conclude, t~~This study showed that distraction distance~~, but not the spatial decay rate of speech,~~ predicts perceived disturbance by noise in open-plan offices. The results support the role of room acoustic design in the attainment of good working conditions in open-plan offices.

Acknowledgments

We wish to thank the following researchers for their input in the workplace measurements and questionnaire development: Anu Kaarlela-Tuomaala, Esko Keskinen, Riikka Helenius,

Comment [HA32]: lisätäänkö tähän jotain muista mittareista, esim. että vaimennukseen liittyviä ei pidä tuijottaa yksin ottamatta taustaäänitasoa huomioon??

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Jukka Keränen, David Oliva and Petra Virjonen. We also thank Prof. Jukka Hyönä for support in the planning of this study and for comments on the manuscript.

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Tables

Table I. Description of the original study designs included in the data.

Study type	Description
Relocation from OPO to OPO	Relocation from one open-plan office to another. Change of building. Acoustic improvement not a goal. Two measurements (before and after).
Relocation from PO to OPO	Relocation from private offices of one person to an open-plan offices. Includes relocations to another building as well as renovations of the existing office. Two measurements (before and after).
Evaluation of OPO acoustic environment	Evaluation of an open-plan office because of noise complaints. One measurement, no follow-up.
Room acoustic improvement	Room acoustic intervention to improve acoustic conditions in an open-plan office. Masking sound installed. Two measurements (before and after).
Office renovation including room acoustic changes	Larger renovation of an open-plan office including changes to several of the following factors: furniture, layout, space efficiency, lighting, back-up spaces (i.e., rooms for privacy and collaboration), thermal conditions, ventilation, environmental control, interior decoration. Room acoustic changes were included but did not necessarily lead to improved acoustic conditions. Two measurements (before and after).

Note. Measurement includes a survey and room acoustic measurements (ISO 3382-3)
OPO = open-plan office, PO = private office

Table II. Summary of the included workplaces.

WP	n	Age, *M (SD)*	Female, %	$D_{2,S}$ (dB)	r_D (m)	Disturbance by noise, high, %	Line of business	Sector	OPO type	Study type	Year	Prior publication
1	66	35.7 (10.0)	65.2	4.0	14.0	45.5	Information technology	PRI	TR	D	2002	Helenius & Hongisto (2004)
2	10	36.4 (10.2)	30.0	8.0	9.0	60.0	Market research	PRI	TR	A	2002	
3	51	36.7 (9.7)	21.6	8.0	9.0	33.3	Engineering services	PRI	TR	B	2003	Kaarlela-Tuomaala et al. (2009)
4	59	44.5 (9.3)	91.5	7.0	9.0	50.8	Banking	PRI	TR	C	2003	
5	66	33.3 (8.1)	43.9	6.5	15.5	70.8	Engineering	PRI	TR	C	2009	
6	20	45.1 (10.6)	35.0	7.5	15.0	60.0	Sales	PRI	TR	C	2008	
7	31	44.1 (10.6)	67.7	11.0	18.0	45.2	Regulation	PUB	TR	A	2008	
8	78	41.8 (9.9)	59.0	10.0	13.0	33.3	Regulation	PUB	TR	A	2008	
9	94	44.4 (10.3)	68.1	8.5	10.0	38.7	Tele-communication	PRI	TR	D	2008	
10	22	40.8 (9.6)	27.3	12.1	9.3	31.8	Training services	PRI	TR	E	2010	Hongisto et al. (2012b)
11	16	40.4 (9.5)	25.0	3.3 & 9.0[a]	12.0	62.5	Engineering	PRI	TR	B	2011	Hongisto et al. (2012b)
12	21	37.0 (12.1)	90.5	10.0	4.8	23.8	Banking and finance	PRI	TR	E	2011	Hongisto et al. (2012a)
13	18	29.6 (4.5)	55.6	6.3	10.0	11.1	Research	PUB	AB	C	2012	
14	31	41.2 (11.9)	12.9	6.3	10.0	46.7	ICT services	PUB	TR	C	2012	
15	23	42.7 (11.4)	87.0	6.3	10.0	21.7	Administration	PUB	TR	C	2012	
16	5	48.4 (10.7)	20.0	7.0	9.0	0.0	State administration	PUB	TR	B	2011	
17	131	46.6 (10.3)	61.8	7.0	14.0	20.3	State administration	PUB	AB	B	2013	
18	12	45.8 (10.0)	91.7	4.2	8.5	16.7	Communications	PUB	TR	B	2013	
19	67	50.6 (10.9)	62.7	7.7	12.0	50.8	Information services	PUB	TR	B	2014	
20	20	45.3 (8.2)	0.0	6.5	6.0	30.0	R&D	PRI	AB	D	2013	
21	47	42.8 (11.3)	38.3	6.5	5.0	6.4	Communication technology	PRI	AB	D	2013	

WP = workplace, PRI = private, PUB = public, OPO = open-plan office, PO = private office, TR = traditional, AB = activity-based
Study types: A = Relocation from OPO to OPO, B = Relocation from PO to OPO, C = Evaluation of OPO acoustic environment, D = Room acoustic improvement, E = Office renovation
Study types are described in Table I. Workplace 11 is considered as two workplaces in the analyses of $D_{2,S}$ and as one workplace in the analyses of r_D. The year refers to the time of the survey from which data is included in the meta-analysis.
[a]WP 11 had two room acoustic values in the analyses of $D_{2,S}$. For 6 respondents, $D_{2,S}$ was 3.3 and for 10 respondents it was 9.0. The corresponding percentages for high disturbance by noise were 66.7 and 60.0, respectively.

WP	n	Age, *M (SD)*	Female, %	Line of business	Sector	OPO type	Study type	Year	Prior publication
1	66	35.7 (10.0)	65.2	Information technology	PRI	TR	D	2002	Helenius & Hongisto (2004)
2	10	36.4 (10.2)	30.0	Market research	PRI	TR	A	2002	
3	51	36.7 (9.7)	21.6	Engineering services	PRI	TR	B	2003	Kaarlela-Tuomaala et al. (2009)
4	59	44.5 (9.3)	91.5	Banking	PRI	TR	C	2003	
5	66	33.3 (8.1)	43.9	Engineering	PRI	TR	C	2009	
6	20	45.1 (10.6)	35.0	Sales	PRI	TR	C	2008	

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7	31	44.1 (10.6)	67.7	Regulation	PUB	TR	A	2008	
8	78	41.8 (9.9)	59.0	Regulation	PUB	TR	A	2008	
9	94	44.4 (10.3)	68.1	Tele-communication	PRI	TR	D	2008	
10	22	40.8 (9.6)	27.3	Training services	PRI	TR	E	2010	Hongisto et al. (2012b)
11	10	37.6 (7.7)	20.0	Engineering	PRI	TR	B	2011	Hongisto et al. (2012b)
12	6	45.2 (11.1)	33.3	Engineering	PRI	TR	B	2011	Hongisto et al. (2012b)
13	21	37.0 (12.1)	90.5	Banking and finance	PRI	TR	E	2011	Hongisto et al. (2012a)
14	18	29.6 (4.5)	55.6	Research	PUB	AB	C	2012	
15	31	41.2 (11.9)	12.9	ICT services	PUB	TR	C	2012	
16	23	42.7 (11.4)	87.0	Administration	PUB	TR	C	2012	
17	131	46.6 (10.3)	61.8	State administration	PUB	AB	B	2013	
18	12	45.8 (10.0)	91.7	Communications	PUB	TR	B	2013	
19	67	50.6 (10.9)	62.7	Information services	PUB	TR	B	2014	
20	20	45.3 (8.2)	0.0	R&D	PRI	AB	D	2013	
21	47	42.8 (11.3)	38.3	Communication technology	PRI	AB	D	2013	

WP = workplace, PRI = private, PUB = public, OPO = open-plan office, PO = private office, TR = traditional, AB = activity-based

Study types: A = Relocation from OPO to OPO, B = Relocation from PO to OPO, C = Evaluation of OPO acoustic environment, D = Room acoustic improvement, E = Office renovation

Study types are described in Table I. The year refers to the time of the survey from which data is included in the meta-analysis.

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Table III. The results of the ISO 3382-3 measurements and the proportion of respondents perceiving high disturbance by noise for each workplace.

WP	r_D (m)	$D_{2,S}$ (dB)	$L_{p,A,S,4\,m}$ (dB)	$L_{p,A,B}$ (dB)	Disturbance by noise in general (high, %)	Disturbance by background speech (high, %)
1	14.0	4.0	50.8	37	45.5	43.9
2	9.0	8.0	44.6	38	60.0	-
3	9.0	8.0	49.6	39	33.3	41.2
4	9.0	7.0	49.3	39	50.8	42.4
5	15.5	6.5	49.6	33	70.8	62.1
6	15.0	7.5	49.9	34	60.0	80.0
7	18.0	11.0	46.6	31	45.2	45.2
8	13.0	10.0	47.3	31	33.3	42.3
9	10.0	8.5	51.3	37	38.7	51.1
10	9.3	12.1	47.8	39	31.8	27.3
11	12.0	9.0	48.9	30	60.0	50.0
12	12.0	3.3	53.8	30	66.7	66.7
13	4.8	10.0	44.3	43	23.8	45.0
14	10.0	6.3	47.8	38	11.1	5.6
15	10.0	6.3	47.8	38	46.7	41.9
16	10.0	6.3	47.8	38	21.7	21.7
17	14.0	7.0	45.8	33	20.3	17.6
18	8.5	4.2	48.2	37	16.7	8.3
19	12.0	7.7	45.8	29	50.8	43.9
20	4.0	7.0	45.3	44.5	30.0	15.0
21	2.5	6.5	44.6	44.5	6.4	8.5

WP = workplace, see Table II

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Table IV. Descriptive statistics for the samples used in the meta-analysis.

Sample characteristic	Complete sample	Activity-based offices excluded
	k=21	k=17
n	880	667
Age, *M*	42.1	41.1
Age, range	20 - 67	20 - 67
Gender, % female	55.9	56.2
High disturbance[a], % overall	37.5	43.8
High disturbance[a], % range	0.0 - 70.8	0.0 - 70.8
r_D, range	4.8 - 18.0	4.8 - 18.0
$D_{2,S}$, range	3.3 - 12.1	3.3 - 12.1

[a]Disturbance by noise in general

Sample characteristic	Complete sample	Activity-based offices excluded
	k=21	k=17
n	875	662
Age, *M*	42.0	41.5
Age, range	20 - 67	20 - 67
Gender, % female	56.1	57.6
Disturbance by noise in general, % overall	37.7	44.5
Disturbance by noise in general, % range	6.4 - 70.8	16.7 - 70.8
Disturbance by background speech, % overall	37.9	44.6
Disturbance by background speech, % range	5.6 - 80.0	8.3 - 80.0
r_D, range	2.5 - 18.0	4.8 - 18.0
$D_{2,S}$, range	3.3 - 12.1	3.3 - 12.1
$L_{A,S,4m}$, range	44.3 - 53.8	44.3 - 53.8
$L_{p,A,B}$, range	29.0 - 44.5	29.0 - 43.0

Table V. Pearson's correlation coefficients for the associations between the main variables of the study. The correlations are based on the workplace level data shown in Table III.

	r_D		$D_{2,S}$		$L_{p,A,S,4m}$		$L_{p,A,B}$		Disturbance by noise in general[a]		Disturbance by background speech[a]
r_D	1										
$D_{2,S}$	0.050		1								
$L_{p,A,S,4\,m}$	0.419		-0.408		1						
$L_{p,A,B}$	-0.831	***	-0.018		-0.384		1				
Disturbance by noise in general[a]	0.543	*	-0.041		0.47	*	-0.563	**	1		
Disturbance by background speech[a]	0.542	*	0.084		0.572	**	-0.516	*	0.877	***	1

* $p < .05$, ** $p < .01$, *** $p < .001$

[a] % in 'high disturbance' category

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Table IVI. The final models for the associations between the room acoustic predictors (r_D and $D_{2,S}$) and the outcome variables adjusted for age and gender. Significant odds ratios (ORs) greater than one indicate an increase in the odds of belonging to the 'high disturbance' category as opposed to 'low disturbance' while odds ratios smaller than one indicate decreased odds. Significant findings are indicated in bold.

Outcome variable		Complete sample (k=21, n=880) OR (95% CI)	p	Activity-based offices excluded (k=17, n=667) OR (95% CI)	p
Disturbance by noise in general	r_D	1.15 (1.04 - 1.26)	0.004	1.12 (1.04 - 1.22)	0.01
	Age[a] 31-50	1.41 (0.92 - 2.16)	0.11	1.32 (0.86 - 2.05)	0.21
	≥ 51	1.54 (0.94 - 2.52)	0.08	1.31 (0.78 - 2.19)	0.30
	Gender[b]	0.89 (0.65 - 1.23)	0.49	0.85 (0.61 - 1.20)	0.36
	$D_{2,S}$	1.02 (0.86 - 1.2)	0.86	0.96 (0.84 - 1.10)	0.57
	Age[a] 31-50	1.42 (0.93 - 2.17)	0.11	1.34 (0.86 - 2.08)	0.20
	≥ 51	1.56 (0.96 - 2.56)	0.08	1.34 (0.80 - 2.25)	0.27
	Gender[b]	0.87 (0.63 - 1.2)	0.41	0.85 (0.60 - 1.20)	0.36
Disturbance by background speech	r_D	1.15 (1.03 - 1.28)	0.01	1.10 (1.02 - 1.19)	0.02
	Age[a] 31-50	1.24 (0.82 - 1.88)	0.31	1.14 (0.74 - 1.75)	0.55
	≥ 51	1.27 (0.78 - 2.06)	0.34	1.16 (0.70 - 1.91)	0.56
	Gender[b]	0.76 (0.55 - 1.04)	0.09	0.79 (0.56 - 1.11)	0.18
	$D_{2,S}$	1.06 (0.89 - 1.27)	0.51	Model failed to converge	
	Age[a] 31-50	1.25 (0.82 - 1.89)	0.30		
	≥ 51	1.28 (0.79 - 2.08)	0.32		
	Gender[b]	0.75 (0.54 - 1.03)	0.08		

[a]Reference category: ≤ 30 years old

[b]Reference category: female

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	Complete sample (k=21, n=875)				Activity-based offices excluded (k=17, n=662)			
	Disturbance by noise in general		**Disturbance by background speech**		**Disturbance by noise in general**		**Disturbance by background speech**	
Predictors	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***
r_D	**1.13 (1.04 - 1.23)**	**0.003**	**1.14 (1.04 - 1.25)**	**0.006**	**1.12 (1.03 - 1.21)**	**0.009**	**1.09 (1.01 - 1.17)**	**0.02**
Age[a] 31-50	1.42 (0.93 - 2.17)	0.10	1.24 (0.82 - 1.89)	0.30	1.33 (0.86 - 2.06)	0.19	1.14 (0.74 - 1.75)	0.55
≥ 51	1.56 (0.96 - 2.55)	0.07	1.28 (0.79 - 2.07)	0.31	1.33 (0.79 - 2.22)	0.28	1.17 (0.71 - 1.93)	0.53
Gender[b]	0.91 (0.67 - 1.26)	0.58	0.78 (0.56 - 1.07)	0.12	0.87 (0.62 - 1.23)	0.43	0.82 (0.58 - 1.14)	0.24
$D_{2,s}$	1.00 (0.84 - 1.19)	0.99	1.07 (0.88 - 1.29)	0.51	0.94 (0.82 - 1.06)	0.32	0.99 (0.88 - 1.12)	0.91
Age[a] 31-50	1.43 (0.94 - 2.18)	0.10	1.25 (0.82 - 1.9)	0.29	1.35 (0.87 - 2.1)	0.18	1.16 (0.76 - 1.79)	0.47
≥ 51	1.58 (0.97 - 2.58)	0.07	1.29 (0.79 - 2.1)	0.31	1.36 (0.81 - 2.29)	0.24	1.20 (0.72 - 1.99)	0.48
Gender[b]	0.89 (0.65 - 1.22)	0.46	0.76 (0.55 - 1.05)	0.10	0.88 (0.62 - 1.24)	0.47	0.81 (0.57 - 1.15)	0.24
$L_{p,\mathrm{A,S,4\,m}}$	**1.20 (1.04 - 1.38)**	**0.01**	**1.27 (1.09 - 1.47)**	**0.002**	1.09 (0.95 - 1.25)	0.23	1.11 (0.98 - 1.26)	0.09
Age[a] 31-50	1.44 (0.94 - 2.19)	0.09	1.26 (0.83 - 1.90)	0.28	1.35 (0.87 - 2.10)	0.18	1.16 (0.75 - 1.78)	0.50
≥ 51	1.60 (0.99 - 2.61)	0.06	1.32 (0.82 - 2.14)	0.26	1.37 (0.82 - 2.31)	0.23	1.22 (0.73 - 2.01)	0.45
Gender[b]	0.90 (0.66 - 1.23)	0.51	0.77 (0.56 - 1.05)	0.10	0.87 (0.61 - 1.22)	0.41	0.81 (0.57 - 1.14)	0.23
$L_{p,\mathrm{A,B}}$	**0.91 (0.84 - 0.98)**	**0.01**	**0.91 (0.84 - 0.98)**	**0.02**	0.93 (0.87 - 1.00)	0.06	0.95 (0.89 - 1.02)	0.16
Age[a] 31-50	1.39 (0.91 - 2.12)	0.13	1.22 (0.80 - 1.87)	0.34	1.30 (0.84 - 2.03)	0.24	1.13 (0.73 - 1.75)	0.58
≥ 51	1.51 (0.93 - 2.47)	0.10	1.25 (0.77 - 2.03)	0.37	1.28 (0.76 - 2.16)	0.35	1.15 (0.69 - 1.92)	0.60
Gender[b]	0.91 (0.66 - 1.24)	0.55	0.77 (0.56 - 1.06)	0.11	0.87 (0.61 - 1.22)	0.41	0.81 (0.57 - 1.14)	0.22

[a]Reference category: ≤ 30 years old

[b]Reference category: female

Figure captions

Comment [HV33]: eli laita kuvat tänne jatkossa normaalisti kuvatekstiä ennen. Jos se on kielletty JASA:ssa, puuttuvat siihen sitten muttei johda hylkyyn. Arvioijana tiedän, miten vaikeaa arviointi on, jos kuvat eivät tästä kohtaa löydy.

Figure 1. a) The spatial decay rate of A-weighted speech level, $D_{2,S}$ describes how steeply the A-weighted level of speech, $L_{A,S}$, reduces when the distance to the speaker, r, is doubled. The curve *a* represents speech levels and the curve *b* represents background noise caused by ventilation. b) Distraction distance, r_D, describes the distance from the speaker where the Speech Transmission Index *STI* falls below 0.50. In both figures, the points describe measurement points in individual workstations located at a distance of r from the speaker. The shown values are examples of possible results.

Figure 2. The principle of the room acoustic measurements (ISO 3382-3) is to imitate a situation in which one person is speaking in a workstation and the voice is heard by others. The measurements are conducted in other workstations at different distances from the speaker.

Figure 3. The percentage of respondents in the 'high disturbance' category at individual workplaces (k=21) in relation to a) the distraction distance, r_D, and b) the spatial decay rate of speech, $D_{2,S}$. Percentages for disturbance by noise in general are shown. Linear interpolations are shown by dashed lines. Pearson's correlation coefficients are 0.52 and 0.02, respectively.

Figure 4. Random intercepts of workplaces for the association between r_D and disturbance by noise in general. The figure refers to the final model of the complete sample (Table IV). The figure shows how much the intercepts of individual workplaces differ from the intercept of the model, i.e. the mean level of workplaces. The scale corresponds to odds ratios. Workplace identification is the same as in Table II.

Figure 5. Random intercepts of workplaces for the association between r_D and disturbance by background speech. The figure refers to the final model of the complete sample (Table IV). The scale corresponds to odds ratios. Workplace identification is the same as in Table II.