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Disruption of writing in noisy office environments

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Abstract

The overall aim of the four experimental studies included in this dissertation was to investigate the influence of background speech on writing performance. In Paper I, a manipulation of speech intelligibility of background speech, by using the Speech Transmission Index (STI), revealed disruptive effects at lower STI values (i.e. with relative low speech intelligibility) than expected, based on an earlier developed model. This showed that writing is more sensitive to disruption from background speech than previously thought.

Experiment 1 in Paper II addressed the question whether the sound of babble, sound of water waves, or pink noise is the most effective and appreciated way of masking background speech to reduce its intelligibility and thereby its disruptiveness. Masking with babble was best. Experiment 2 in Paper II followed this finding up by showing that the disruption of writing by background speech is a function of the number of voices talking in the background—less voices, more disruption.

Paper III investigated the combined impact of background speech and task interruptions on writing performance. Background speech (which was played during the whole condition) after an interruption was expected to prolong the time it took to resume the same writing speed as before the interruption. This hypothesis was not confirmed, but participants' self-reports showed that the combination of task interruptions and background speech convey a particularly high workload.

Paper IV explored what role sound source location and individual differences (inattention, noise sensitivity and working memory capacity) play in the disruption of writing by background speech. Self-reports showed that speech in front of the individual was perceived as more distracting compared to speech from behind. Other results in the same study showed that high inattentive individuals profit more from less intelligible speech located behind them than attentive individuals and high noise-sensitive individuals were more distracted by highly intelligible background speech than by less intelligible background speech.

The most important and replicable finding in this dissertation is that writing fluency is very sensitive to disruption from background speech; a finding relevant for the design of open work environments. In work areas where writing is a common task, the aim should be to create quiet work areas.

Keywords: background speech, writing, speech intelligibility, Speech Transmission Index, masking, sound source location, working memory capacity, inattention, noise sensitivity, task interruptions

Sammanfattning

Huvudsyftet med de fyra experimentella studierna som den här avhandlingen omfattar var att studera hur bakgrundsprat påverkar skrivandet av en text. I Artikel I manipulerades taluppfattbarheten (Speech Transmission Index; STI) i bakgrundspratet genom att till olika grad maskera talljudet med ett brusljud. Ljudet spelades sedan upp medan deltagarna arbetade. Resultaten visade att störningarna i skrivprocessen uppträder redan för lägre STI värden (d.v.s. redan vid låg taluppfattbarhet) än vad som förväntades baserad på en tidigare utvecklad modell.

Experiment 1 i Artikel II studerade vilket ljud (babbel, vågor eller brus) som är det mest effektiva och uppskattade för att maskera bakgrundsprat och reducera taluppfattbarhet i bakgrundsprat. Resultaten visade att babbel var bäst. Experiment 2 i Artikel II följde upp det här resultatet genom att visa att störningen från bakgrundsprat vid skrivande beror på antalet personer som pratar samtidigt i bakgrunden - färre röster, mer störning.

Artikel III fokuserade på hur skrivandet påverkas av att det, utöver bakgrundsprat, även finns andra avbrott i skrivuppgiften. Hypotesen var att bakgrundsprat (som spelades upp under hela betingelsen) direkt efter avbrottet skulle öka tiden det tar att nå samma skrivhastighet som före avbrottet. Den här hypotesen bekräftades inte, men deltagarnas självskattningar visade att kombinationen av avbrott och bakgrundsprat leder till en upplevelse av ökad arbetsbelastning.

Artikel IV undersökte huruvida ljudkällans position i rummet, samt individuella skillnader (uppmärksamhet, arbetsminneskapacitet och ljudsensitivitet) modererar hur bakgrundsprat påverkar skrivandet. Självskattningar visade att bakgrundsprat som kommer framifrån upplevs som mer störande än bakgrundsprat som kommer bakifrån. Resultaten visade även att personer som har en låg förmåga att bibehålla uppmärksamheten gynnades mer av bakgrundsprat med låg taluppfattbarhet som kom bakifrån än personer som har hög förmåga att bibehålla uppmärksamheten. Vidare var ljudkänsliga individer mer distraherade av bakgrundsprat med högre taluppfattbarhet, jämfört med lägre taluppfattbarhet.

Det viktigaste resultatet, som även replikerades mellan de olika studierna i den här avhandlingen, är att skrivprocessen är mycket känslig för bakgrundsprat; ett resultat som är relevant vid design av t.ex. öppna kontorslandskap. I arbetsomgivningar där skrivuppgifter är vanligt förekommande, bör tysta utrymmen skapas.

Nyckelord: bakgrundsprat, skriva, taluppfattbarhet, Speech Transmission Index, maskering, ljudposition, arbetsminneskapacitet, uppmärksamhet, ljudkänslighet, uppgiftsavbrott

Samenvatting

Het doel van de vier experimentele studies in dit proefschrift was om te onderzoeken hoe achtergrondgeluid het schrijven verstoort. In Artikel I toonde een manipulatie van de verstaanbaarheid van het spraaksignaal (m.b.v. Speech Transmission Index; STI) aan, dat de storende effecten van spraak op de achtergrond al optreden bij lagere STI waardes (d.w.z. al bij een lage verstaanbaarheid) dan wat op basis van een eerder ontwikkeld model werd verwacht. Dit betekent dat schrijven gevoeliger is voor storingen veroorzaakt door spraak op de achtergrond dan eerder werd gedacht.

Experiment 1 in Artikel II onderzocht of geluid van golvend water, gebabbel, of ruis de meest effectieve en gewaardeerde manier is om spraak op de achtergrond te maskeren en de verstaanbaarheid te verminderen. Gebabbel was het best. Experiment 2 in Artikel II volgde dit resultaat op en toonde aan dat storingen in het schrijven veroorzaakt door gepraat op de achtergrond afhankelijk is van het aantal personen dat tegelijk praat – minder stemmen, meer storing.

In Artikel III werden taakonderbrekingen in het schrijven toegevoegd om te onderzoeken of spraak op de achtergrond (dat gedurende de hele conditie werd afgespeeld) de tijd die het kost om na de onderbreking dezelfde schrijfsnelheid weer op te pakken verlengt. Deze hypothese werd niet bevestigd, maar zelfrapportages van de onderzoeksdeelnemers toonden aan dat de combinatie van taakonderbrekingen en gepraat op de achtergrond leiden tot een hoge werkdruk.

Artikel IV onderzocht of individuele verschillen (i.e. onoplettendheid, werkgeheugencapaciteit en geluidsgevoeligheid) en de positie van de geluidsbron een rol spelen in de relatie tussen spraak op de achtergrond en schrijven. Zelfrapportages toonden aan dat spraak die van voren komt werd beschouwd als meer storend dan spraak die van achteren komt. Andere resultaten in dezelfde studie toonden aan dat personen met lagere oplettendheid meer profiteren van spraak met lagere verstaanbaarheid van achteren dan personen met grotere oplettendheid en dat geluidsgevoelige personen meer afgeleid worden door spraak met betere dan met een slechtere verstaanbaarheid.

De bevinding dat schrijven zeer gevoelig is voor spraak op de achtergrond, wordt door alle studies ondersteund en is de belangrijkste conclusie. Een relevante bevinding voor het ontwerp van open werkomgevingen. In werkomgevingen waar veel geschreven wordt zou naar stilte gestreefd moeten worden.

Trefwoorden: gepraat op de achtergrond, schrijfprestatie, verstaanbaarheid, Speech Transmission Index, maskeren, geluidspositie, werkgeheugencapaciteit, oplettendheid, geluidsgevoeligheid, taakonderbreking

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List of papers

This thesis is based on the following papers, which are referred to in the text by Roman numerals.

Paper I

Keus van de Poll, M., Ljung, R., Odelius, J., & Sörqvist, P. (2014). Disruption of writing by background speech: The role of Speech Transmission Index. *Applied Acoustics*, 81, 15-18, doi: 10.1016/j.apacoust.2014.02.005

Paper II

Keus van de Poll, M., Carlsson, J., Marsh, J.E., Ljung, R., Odelius, J., Schlittmeier, S.J., Sundin, G., & Sörqvist, P. (2015). Unmasking the effects of masking on performance: The potential of multiple-voice masking in the office environment. *The Journal of the Acoustical Society of America*, 138, 807-816, doi: 10.1121/1.4926904

Paper III

Keus van de Poll, M., & Sörqvist, P. (2016). Effects of task interruption and background speech on word processed writing. *Applied Cognitive Psychology*, 30, 430-439, doi: 10.1002/acp.3221

Paper IV

Keus van de Poll, M., Sjödin, L., & Nilsson, M.E. (submitted). Disruption of writing by background speech: Does sound source location, working memory capacity, noise sensitivity, inattention and number of voices matter?

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Introduction

Noise in the open-office environment

The office building might have been one of the most important building types of the 20th century as more than half of the working population in the Western World spends large parts of the day in an office (Van Meel, 2000). In the 1960s, the open-plan office (i.e. a large space designed to accommodate a large amount of workers, workplaces can be divided by freestanding partitions) gained popularity as it was a way to build more efficient organizations compared to cell-offices (i.e. individual rooms divided by permanent walls). Since then, there have been shifts in whether open offices or cell-offices were the most popular office-designs (see Bodin Danielsson, 2010, and Van Meel, 2000, for more detailed historical reviews). A financial advantage with building open-plan offices is the lower cost per square meter per employee compared to cell offices. Other advantages could arguably be an increase in communication, improvements of social relations between coworkers and thereby an increase in motivation and job satisfaction (see Oldham & Brass, 1979, for a review). On the other hand, disadvantages could be that the absence of walls and other physical boundaries in the open-plan office may lead to a loss of privacy and increased likelihood for external intrusions, like people talking in the background or colleagues asking questions (Oldham & Brass, 1979).

Research on perceptions of the indoor environment in open offices has shown that workers perceive noise as one of the most disturbing factors (Banbury & Berry, 2005; Boyce, 1974; Danielsson & Bodin, 2009; De Croon, Sluiter, Kuijer, & Frings-Dresen, 2005; Kim & De Dear, 2013). Noise is annoying (Banbury & Berry, 2005; Sundstrom, Town, Rice, Osborn, & Brill, 1994), it decreases motivation (Evans & Johnson, 2000), decreases satisfaction with the work environment (Sundstrom et al., 1994), it can be stressful (Babisch, 2003; Smith, 1991), it impairs perceived mental workload (Smith-Jackson & Klein, 2009) and it impairs cognitive performance (Loewen & Suedfeld, 1992; Sundstrom et al., 1994).

The problem with noise in open offices is complicated as several factors play a role in whether noise will be disruptive for performance and how sensitive a task is to disruption via the noise. One factor important in whether noise will influence cognitive performance is the nature of the sound. For instance, research focused on the impact of environmental noise on cognitive performance showed impaired cognitive performance for children chronically exposed to aircraft noise (Hygge, Evans, & Bullinger, 2002; Evans, Hygge, & Bullinger, 1995; Haines, Stansfeld, Brentnall, et al., 2001; Haines, Stansfeld, Soames Job, Berglund, & Head, 2001; Clark, et al., 2005; Stansfeld et al., 2005). The effects of road-traffic noise, on the other hand, appear to be more variable as studies have shown both that it can improve (Stansfeld, et al., 2005)

and impair cognitive performance (Hygge, Boman, & Enmarker, 2003). Another source of noise, commonplace in for instance schools and offices, is meaningful task-irrelevant background speech. Several studies have shown that among all sources of office noise (e.g., people talking, telephones ringing, ventilation noise, noise of machinery, sound of footsteps and scraping chairs) open office workers perceive task-irrelevant background speech, like colleagues having conversations in the background, as the most disruptive noise factor (Banbury & Berry, 2005; Boyce, 1974; Haapakangas, Helenius, Keskinen, & Hongisto, 2008; Kaarlela-Tuomaala, Helenius, Keskinen, & Hongisto, 2009; Young & Berry, 1979). To investigate whether a low intensity sound like speech could be as disruptive for cognitive performance as high intensity sounds like aircraft and road traffic noise, several studies compared meaningful task-irrelevant speech with environmental noise like aircraft and road traffic noise (Enmarker, 2004; Hygge et al., 2003; Ljung, Sörqvist, & Hygge, 2009; Sörqvist, 2010). Both road traffic noise and meaningful task-irrelevant speech disrupted cognitive performance in both children and adults. Though, within a group of adults with ages between 35 and 65 there were no differences in performance (Enmarker, 2004; Hygge et al., 2003; Ljung et al., 2009). Sörqvist (2010) explored differences between effects of aircraft noise and task-irrelevant speech on prose memory in adolescents and found that speech impaired prose memory performance more compared to aircraft noise. Taken together, these studies suggest that speech is the most disruptive noise source for work within the built environment.

The finding that task-irrelevant speech can impair cognitive performance is relevant in open-office workplaces as task-irrelevant background speech is commonplace in such environments. There is a large spectrum of cognitive tasks with relevance for office work, e.g. writing, reading and mathematics. As mentioned above, whether noise has an impact on cognitive performance or not, and the direction and the magnitude of this impact, depends not only on the nature of the sound, but also on the nature of the task. Tasks that are easily disrupted by task-irrelevant speech are less suitable to be performed in open office environments compared with tasks that are not easily disrupted by task-irrelevant speech. Jahncke (2012) studied whether the presence of task-irrelevant speech impaired different cognitive tasks relevant for office work. Tasks based on short-term memory and rehearsal, like memory of words and searching for information, were more disrupted by task-irrelevant speech compared to tasks that were not based on rehearsal or tasks based on long-term memory retrieval, like arithmetic and word generation. Other studies have shown impairing effects of task-irrelevant speech on tasks like reading comprehension (Halin, Marsh, Hellman, Hellström & Sörqvist, 2014; Martin, Wogalter, & Forlano, 1988; Sörqvist, Halin, & Hygge, 2010) proofreading (Halin, Marsh, Haga, Holmgren, & Sörqvist, 2014; Jones, Miles, & Page, 1990; Smith-Jackson, Klein & Wogalter, 1997; Venetjoki, Kaarlela-Tuomaala, Keskinen, & Hongisto, 2006) and memory tasks, like serial recall and text memory (Haapakangas, Hongisto, Hyönä, Kokko, & Keränen, 2014; Haka, et al., 2009). Some of these studies have shown that it is the speech intelligibility (i.e. the possibil-

ity to hear what is said within the background speech) that gives rise to disruption to focal task processes; speech with high speech intelligibility was more disruptive compared to speech with low intelligibility (Haka et al., 2009; Hongisto, 2005; Jahncke, Hongisto, & Virjonen, 2013).

Beside the relevant office tasks that have been studied in relation to task-irrelevant background speech, like reading comprehension, proofreading and prose memory, another relevant office task is writing. In most professions, employees have to write notes, e-mails or reports. Despite the fact that writing is perhaps one thing that office workers spend most of their time doing, only a few studies (Ransdell & Gilroy, 2001; Ransdell, Levy, & Kellogg, 2002; Sörqvist, Nösth, & Halin, 2012) have explored the relationship between background sounds and writing. Because writing is such a common task, and language-based tasks are particularly sensitive to disruption from background speech, it is highly relevant to investigate the impact of task-irrelevant speech on writing. It may well reveal that office-work such as writing is more sensitive to disruption from background speech than previously believed. Writing is therefore the focus of the papers included in this dissertation.

Speech Transmission Index

Studies have concluded that it is the speech intelligibility of the speech signal that is disruptive for cognitive performance (Haka et al., 2009; Hongisto, 2005; Jahncke et al., 2013). These studies have manipulated speech intelligibility by using the Speech Transmission Index (STI) (Houtgast, Steeneken, & Plomp, 1980). STI is a well-established way to measure the degree of speech intelligibility in a speech signal. It measures the transmission of speech from a talker to a listener by a transmission channel (IEC 60268-16). It takes into account the size of the room, the reverberation time and the distance between the talker and the receiver. STI ranges from 0 (no speech intelligibility at all) to 1 (perfect speech intelligibility). Based on several studies which have shown how speech influences performance (e.g. Banbury & Berry, 1998; Buchner, Steffens, Irmen, & Wender, 1998; Colle & Welsh, 1976; Martin et al., 1988; Salamé & Baddeley, 1989; Weinstein, 1977), Hongisto (2005) developed a model to predict the relationship between STI and cognitive performance. International recommendations for acoustics in open offices (ISO 3382-3) are based on this model. The model suggests that the largest drop of performance occurs between a STI of 0.20 and 0.50 (see Figure 1). This is why STI within a work environment should not exceed 0.50 according to the international recommendations (ISO 3382-3).

Since the time when the model was introduced by Hongisto (2005) several studies have used it to check whether it can predict performance decrements for a range of cognitive tasks (Ebissou, Parizet, & Chevret, 2015; Haapakangas et al., 2011; Haka et al., 2009; Jahncke et al., 2013; Venetjoki et al., 2006). The results of some of those studies have shown that for some tasks, like a task on word memory and math, the major drop in performance occurred between STI 0.23 and 0.34 (Jahncke et al., 2013) and for a short-term memory task, the major drop in performance occurred between STI 0.25 and 0.45 (Ebissou et

al., 2015). Hence, both studies show that the largest decrease of performance occurred at lower STI values than Hongisto (2005) suggested. As writing is sensitive to background speech (Ransdell et al., 2002; Sörqvist et al., 2012) and as the model of Hongisto not yet had been applied on a writing task, arguably an important and relevant office-task, the main aim of Paper I was to investigate whether writing performance decrements kick in at relatively low STI levels. To understand why writing should be impaired by speech intelligibility, it is first important to learn why noise in general can impair cognitive performance. This issue is turned to in the next section.

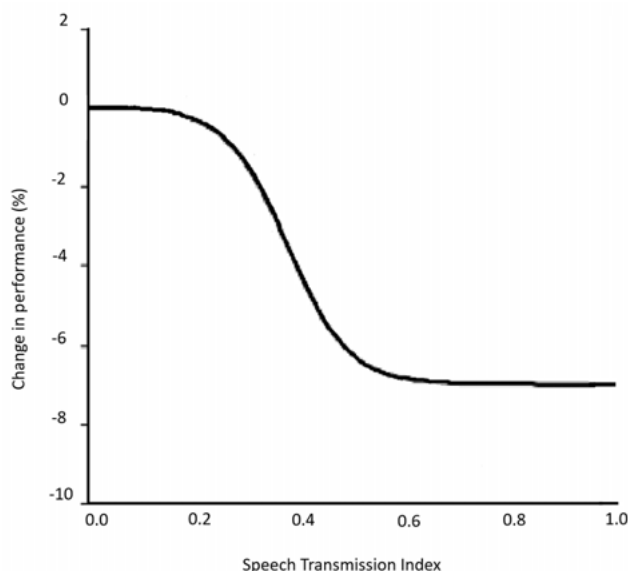


Figure 1. The relationship between Speech Transmission Index and the change in performance (in %). Modified from Jahncke et al. (2013).

Why is noise disruptive?

When we do not want to see something that is happening nearby us, we only have to close our eyes. On the other hand, when we do not want to hear something, we cannot just block our ears as the brain automatically analyzes and processes attended and unattended incoming auditory signals (Hughes & Jones, 2003). In some cases, this inability to exclude the sound from reaching us naturally is vital, like when a fire alarm is ringing. However, in a lot of cases, task-irrelevant background sound is not directly related to survival, but still, colleagues talking with each other or someone talking in the phone can be annoying (Banbury & Berry, 2005) and disruptive for performance (Jahncke et al., 2013; Jahncke, Hygge, Halin, Green, & Dimberg, 2011; Marsh & Jones, 2010). But what is it that makes sound disruptive? A classical way to study distraction by noise is by using a serial recall task, which is a typical short-

term memory test. In this test, a series of stimuli, for instance words, is presented sequentially and in random order on a computer screen for a very short period, like 500 ms per stimuli. After the presentation of the stimuli, the individual has to recall the stimuli in the order of presentation. Task performance decreases when a task-irrelevant sound is played during the presentation of the visual stimuli (Banbury, Macken, Tremblay, & Jones, 2001; Beaman, 2004). The magnitude of the disruption depends on the acoustic variability of the auditory signal. Sound signals with almost no acoustic variability (i.e. a steady-state sound), like 'B B B B B' are -almost- not distracting at all. Performance while exposed to a steady-state sound is similar to performance in a quiet condition. On the other side, a sound signal with high acoustic variability, like 'B N L K C' (i.e. a changing-state signal) impairs serial recall performance (Bell, Dentale, Buchner, & Mayr, 2010; Campbell, Beaman, & Berry, 2002; Hughes, Tremblay, & Jones, 2005; Jones & Macken, 1993). This difference between steady-state and changing-state sound conditions is called the changing-state effect (Jones & Macken, 1993). Even speech and music can provoke a changing-state effect and impair performance as long as there is acoustical variation in the signal (e.g. varying frequency and pitch; Jones & Macken, 1993; Salamé & Baddeley, 1990).

Besides the acoustical variability in the sound signal, abrupt changes in the sound signal, like a novel or deviant aspect, can disrupt serial recall (Hughes, Vachon, & Jones, 2005). For example, a signal consisting of 'C C C C C' is not distracting while the F in a 'C C C F C' signal is distracting and decreases recall performance because of the violation of the expectation for another C. This is called the deviation effect (Hughes, 2014; Hughes, Vachon, & Jones, 2005; Hughes, Vachon, & Jones, 2007). Not only deviant aspects has shown to be distracting, even other aspects that in some way are relevant or interesting for the recipient (like hearing your own name in a background conversation; Conway, Cowan, & Bunting, 2001) have been shown to be distracting. The deviant or the personally significant sound capture attention and draw attention away from the focal task towards the task-irrelevant background sound (e.g. Dalton & Hughes, 2014; Hughes, 2014; Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013; Lange, 2005; Röer, Bell, & Buchner, 2013; Sörqvist, 2010).

According to some researchers (Bell, Röer, Dentale, & Buchner, 2012; Cowan, 1995), the reason why the changing-state effect and the deviation effect impairs serial recall is the abrupt changes in the auditory material that elicit orienting responses and draw away attention from the task to the auditory material (i.e. attentional capture). As a result, an impairment in serial recall performance occurs, as the to-be-remembered items in the serial recall task become unattended. A steady-state sound should be less distracting compared to a changing-state sound, as repeated exposure to the same auditory signal causes habituation to the orienting response (Cowan, 1995). Hence, according to this explanation of the two effects, the two effects are underpinned by the same mechanism.

Problematic with this explanation is that the changing-state effect only occurs when a task demands serial order processing while the deviation effect occurs even on other tasks, like in free recall (where the same stimuli as in

serial recall are presented but can be recalled in any order) (Hughes et al., 2007; Parmentier, 2008). The absence of a changing-state effect but the presence of a deviation effect in the context of free recall is difficult to explain by assuming that both effects are underpinned by attention capture. An alternative explanation of the changing-state effect is a conflict between the automatically processing of the sound signal and similar processes that are needed to perform on the target task. In the case of serial recall, seriation processes that represent the order of different objects in the background sound signal interfere with similar processes needed to memorize the order of the to-be-remembered stimuli. This explanation of auditory distraction is referred to as interference-by-process (Macken, Tremblay, Alford, & Jones, 1999). On this view, there is no single mechanism that underpins the changing-state and the deviation effect. Instead, this view assumes a duplex-mechanism account, whereby attentional capture explains the deviation effect, but interference-by-process explains the changing-state effect (Hughes, 2014).

Background speech as a distractor for writing processes

As mentioned before, speech has been reported as one of the most distracting background sound signals in open offices (Banbury & Berry, 2005; Boyce, 1974), especially for language-related tasks like reading and writing (Haapakangas et al., 2008; Kaarlela-Tuomaala, et al., 2009). So, why is speech especially distracting?

Speech is, as all other sounds, a wave motion in air with acoustic properties, like the amplitudes and frequencies of the sound wave (Everest & Pohlman, 2015). Beyond the acoustic properties, speech has also semantic properties, like the words and sentences, which are about the meaning of the speech (Akmajian, Demers, Farmer, & Harnish, 2001). Reasonably, it is the semantic properties that make background speech distinct from other non-speech sounds, as all sounds have acoustic properties but the brain extracts semantic meaning only from speech sound. To understand why background speech can disrupt performance on language-related tasks like writing, it is essential to consider the cognitive processes involved in the writing task.

Writing is a task that demands higher-order thinking. In general, higher-order thinking means that new information together with information that already is stored in memory are rearranged and extended with the aim to reach a goal or find possible answers in complicated situations (Lewis & Smith, 1993). In the case of writing, cognitive processes that are involved are semantic related processes like generation and organization of ideas and the transformation of these ideas into a story that has to be reviewed and rewritten until it reaches a final form (Hayes & Flower, 1980).

One view on how background speech can disrupt writing is that verbal information from the sentence construction in the writing process and verbal information from the background speech signal is automatically and temporarily stored in a part of working memory. According to Baddeley (2000), working memory is a limited capacity system for both processing and temporary storage

of information. This temporary storage is suggested to contain four components; the phonological loop (for temporary storage of verbal and acoustical information), the visuospatial sketchpad (for temporary storage of visual information), the episodic buffer (which functions as a temporary storage with the capability to integrate information from different sources) and the central executive (to control and regulate the other three functions). Salamé and Baddeley (1982) suggested that it is in the phonological loop that phonological information from unattended speech sound meets and interferes with phonological information from attended visually presented items. The phonological similarity between the phonological information of the background speech and the visually presented items causes disruption of performance. Since phonological information involved in writing processes is temporarily stored in the phonological loop (Kellogg, 1996; Kellogg, Olive, & Piolat, 2007), reasonably, background speech should disrupt writing performance because of the phonological similarity between the phonological information of the background speech and the phonological information from the writing process. Because highly intelligible background speech contains more phonological information compared to less intelligible background speech, highly intelligible speech should be more disruptive.

The disruption of cognitive performance by unattended speech caused by phonological similarity between the unattended auditory information and the attended visual material is based on interference between different kinds of verbal information (e.g. auditory versus written information) that have similar contents. It should be mentioned, though, that research has shown that it is rather interference between processes, and not between contents, that underpins the disruption of speech on semantic-based tasks (Marsh, Hughes, & Jones, 2009). The most important support for the interference-by-process view is that the magnitude of disruption by background speech depends on what the participants ‘do’ with the to-be-recalled information, but not on the ‘identity’ of the to-be-recalled information (Marsh, Hughes, & Jones, 2008, 2009). Regardless of whether phonological similarity or semantic similarity between the background speech and the task-material underpins the disruption, speech should be more disruptive to writing than non-speech sound.

In line with the interference-by-process account, background speech should disrupt writing because of a conflict between the semantic processes involved in the writing task and similar processes engaged in the automatic analysis of the semanticity of background speech. As speech also is a changing-state sound and as some serial ordering is needed in writing (like arranging words and letters in a specific order), a changing-state effect, i.e. interference between the serial order processes, might also occur. However, Sörqvist et al. (2012) showed that it is the semantic characteristics of speech rather than the acoustical characteristics (the sound’s acoustic variability or change) that makes speech disruptive for writing. They exposed students to spectrally rotated speech, quiet and normal speech while the students were writing stories. When transforming a normal speech signal into a spectrally rotated version, the acoustic characteristics are maintained, but the high-frequency energy of the

normal speech is transformed into low-energy and vice versa. This makes the spectrally rotated signal incomprehensible while the physical characteristics (e.g. pause durations between words and sentences) are highly similar to the normal speech signal. If it were the acoustic characteristics that were more disruptive compared to the semantic characteristics, there should be no differences between normal and rotated speech with regard to their effects on writing, as normal and rotated speech have similar acoustic characteristics. The results showed though that performance was worst in the normal speech situation while there were no differences between the spectrally rotated speech and the quiet condition. Hence, it is the semantic characteristics rather than the acoustic characteristics that disrupt writing performance. This means that a speech signal consisting of more semantic information and highly intelligible speech should be more disruptive compared to signals that contain less semantic information or less intelligible speech.

Paper I, II and IV of this dissertation investigated the impact of speech intelligibility and semantic information in background speech on writing by manipulating the STI by masking the sound in various ways. Furthermore, in Experiment 2 in Paper III, the semantic information of the background speech was manipulated by comparing the effects of dialogues and halfalogues. In the dialogue, two people had a telephone conversation where both parts of the conversation could be heard, while in the halfalogue only one part of the conversation was audible. As dialogues contain more semantic and phonetic information, dialogues should be more distracting compared to halfalogues according to the interference-by-process as well as the interference-by-contents account. However, self-report studies on annoyance and distraction of halfalogues versus dialogues have suggested that halfalogues are more distracting compared to dialogues, possibly because halfalogues capture attention to a higher degree than dialogues. The reason for this could be a higher need-to-listen and participants' will to predict what the conversation is about in halfalogues (Norman & Bennett, 2014), or because of the unpredictability of halfalogues compared to dialogues (Emberson, Lupyan, Goldstein, & Spivey, 2010). Studies exploring the impact of halfalogues and dialogues on annoyance and distraction have investigated the effects on an anagram task (Galván, Vessal, & Golley, 2013), a reaction time task and a visual monitoring task (Emberson et al., 2010), or no task at all (Norman & Bennett, 2014). Thus, previous studies have been limited, and it is unclear whether halfalogues or dialogues should be more distracting to a more applied and continuous task like writing. Therefore, Experiment 2 in Paper III explored whether halfalogues or dialogues are more distracting for performance on a writing task.

Masking of noise

Since problems with noise and privacy arose in open offices, several attempts have been done to solve the problem, e.g. the use of absorbing panels in the ceilings, screens between the workstations, organizing workstations in different groups, agreements about where to use telephones and agreements about

conversation speech levels (Virjonen, Keränen, Helenius, Hakala, & Hongisto, 2007; Virjonen, Keränen, & Hongisto, 2009). Another solution is to try to mask background speech by playing another kind of sound. It is not unusual that individuals choose to listen to music as a mask for task-irrelevant background sound when trying to concentrate on a cognitive task (Haake, 2011). However, studies on the impact of music on cognitive performance have found that especially vocal music, but even instrumental music, is disruptive for cognitive performance (Haapakangas et al., 2011; Perham & Currie, 2014). This is in line with the interference-by-process and attentional capture account.

From a cognitive perspective, however, it should be possible to reduce the effects of background speech by masking it, since the acoustic variability of the sound that reaches the ear thereby reduces, as well as it constrains intelligibility of the speech signal. A more effective way of masking, applied by many organizations, might therefore be to use broadband noise as a masker, by playing it through loudspeakers in the office (Schlittmeier & Hellbrück, 2009). When broadband noise is added to a speech signal, the abrupt changes in loudness and pitch are masked. Consequently, this reduces the acoustical variability and the speech intelligibility of the signal that reaches the listener. Another way to reduce the changing-state characteristics of a background speech signal is to mask it with other changing-state-signals, like other speech signals, i.e. babble (Jones & Macken, 1995). Adding voices to a speech signal reduces the perceivable changes between successive sounds and consequently also the changing-state effect and speech intelligibility. Research has shown that the impairing effects of speech on performance attenuates when as few as four voices are masking each other and that it is further reduced when the number of voices goes up to five, six or more (Jones & Macken, 1995; Zaglauer, Drotleff, & Liebl, 2017). These findings are in line with the theory of interference-by-process and attentional capture as more people talking simultaneously reduces speech intelligibility and thereby the possibility that deviant/interesting aspects in the speech signal capture attention. Therefore, in a sense, masking can function as a shield against performance decrements.

Masking background sound with continuous noise, like broadband noise, has been shown to be effective in reducing impairing effects of background sound (Hongisto, 2008; Schlittmeier & Hellbrück, 2009). It is also perceived as less disturbing compared to background sound without any masking (Hongisto, 2008; Schlittmeier & Hellbrück, 2009). However, masking sound can be perceived as more disturbing compared to quiet (Schlittmeier & Hellbrück, 2009), as people do not seem to prefer additional noise in the background (Schlittmeier & Hellbrück, 2009). Furthermore, when both preferences and effectiveness of masked speech are measured in the same study, the reported preferences do not always match the objective data on performance. For example, Schlittmeier and Hellbrück (2009) showed that continuous noise was more effective compared to legato music with regard to cognitive performance, but participants seemed to prefer legato music. In Haapakangas et al., (2011), four maskers (i.e. spring water, instrumental music, vocal music and ventila-

tion noise) were compared to investigate how they influenced serial recall performance and perceived acceptance for the sound environment. They found that vocal music was less appreciated and less effective compared to instrumental music and the sound of water. Performance in conditions with spring water as a mask was not significantly different from performance in quiet. Despite the effectiveness of the sound of spring water as a mask, the acceptance of this type of mask was significantly lower compared to quiet.

The different studies described here indicate that sounds from nature, like the sound of spring water and multiple voices, have the potential to be effective maskers and can be alternatives to continuous noise. It is, however, still a lack of studies which have compared the effectiveness and appreciation of a masking sound from nature, multiple voices and continuous noise within the same study. Therefore, the aim of Paper II in this dissertation was to find a way to mask background speech that is more effective and more appreciated than masking by broadband noise, by comparing broadband noise with sound from nature (i.e. the sound of water waves) and the sound of multiple voices (i.e. people talking simultaneously).

Sound pressure level

When a masking sound is added to speech, the masking sound adds to the general sound pressure level. It is plausible to think that higher sound levels are more annoying and more distracting, especially for higher-order cognitive tasks like writing. Therefore, despite the fact that masking is able to reduce speech intelligibility, the higher sound pressure level might lead to a decrease in performance and an increase in annoyance. However, results are not completely consistent as some studies did find that the relation between office noise (other than speech) and annoyance or the impairment of performance caused by task-irrelevant sounds did not depend on the loudness of the sound (Colle, 1980; Ellermeier & Hellbrück, 1998; Jones et al., 1990; Landström, Åkerlund, Kjellberg, & Tesarz, 1995). In contrast, Jahncke et al. (2011) showed that both memory and non-memory tasks were impaired when office noise levels were 51 dBA compared to office noise levels of 39 dBA (a typical sound level in open offices is around 50 dBA; Venetjoki et al., 2006). In Experiment 2 in Paper II the sound pressure level increased for the number of voices masking each other, with highest sound pressure level for seven simultaneously talking voices and lowest level for one single voice talking. The expectation was that speech intelligibility should be more disruptive compared to sound level, thus that performance should decrease as a function of increasing speech intelligibility. On the other side, if sound pressure level would impair performance more than speech intelligibility, task performance should decrease as a function of an increase in number of masking voices.

Background speech as task interruption: a shift in attention

Each time a deviant aspect in the background sound captures our attention, an interruption in the attended task occurs. For individuals working in a noisy environment this can lead to many task interruptions during a workday. It's not

only background speech that interrupts focal task activity, there are also other sources of interruption like colleagues asking questions, ringing telephones and emails we have to respond to immediately. For instance, a study identified interruptions for a group of meteorologists in a naturalistic situation. Task interruptions occurred every 40 seconds over a 2-hour period (Trafton & Monk, 2007). Each time an interruption occurs, by task-irrelevant background sound or by another source of interruption, attention is shifted from the focal task to the interrupting factor. In the time period between the end of the interruption to the point when the focal task is resumed (i.e. the resumption lag, see Figure 2), several processes take place. We have to reallocate attention from the interruption task to the focal task, we have to re-orientate on the focal task (recall or figure out where to pick up the task), and determine how to move on to fulfill the goal we had before the interruption (Trafton & Monk, 2007). In other words, we have to regain situation awareness (Endsley, 1995).

To resume a task after the end of an interruption, the (sub-)goals of the focal task have to be reactivated, as the most active goal in memory directs behavior (Altmann & Trafton, 2002). The construct of activation is used to improve our understanding of goal-directed cognition. During planning, we divide the ultimate goal in several smaller sub-goals that are easier to achieve. Later, after achieving the smaller goals, we reactivate the ultimate goal. In this phase, it is important with priming from cues to avoid interference with other, newer goals in memory. This goal activation model (Altmann & Trafton, 2002) is traditionally illustrated with the Tower of Hanoi problem. In this game, a certain amount of disks with sizes from small (at the top) to large (at the bottom) are placed on one of three pegs. The ultimate goal is to move the disks to a certain peg, one by one, with as few moves as possible. As larger disks are not allowed to rest on smaller pegs, planning and creating of sub-goals is needed to reach the ultimate goal. A sub-goal for example could be to first calculate to which peg the first disk should be moved. In case of interruptions, the goal activation model predicts that the time between the alert for the interrupting task and the start of it (i.e. interruption lag, see Figure 2) plays an important role in the capability to resume an interrupted goal. Decay will occur gradually for suspended goals (Altmann & Trafton, 2002; Trafton & Monk, 2007), but the amount of rehearsal of the focal task during the interruption lag and, if possible, during the interruption, will help to keep the goals related to the focal task activated. Hence, the length of the interruption can predict the resumption lag; longer interruptions are related to more decay of the goals related to the focal task. The more the interruption prevents rehearsal of the focal task, the more disruptive the interruption will be. Consequently, resumption time will be longer (Hodgetts & Jones, 2006; Monk, Trafton, & Boehm-Davis, 2008).

Both background speech and task interruptions have in common that they capture attention and require a shift in attention from the task to the interruption and back to the task. In Paper III, we argued that when both background speech and other task interruptions are present in the context of a writing task, the distracting effects should add to each other. Consequently, it will be harder to re-orientate on the focal task after a task interruption. The presence of background speech during this period of re-orientation will make it harder to regain

situation awareness. Therefore, background speech should prolong the time it takes to resume the same writing speed as before the interruption.

To our knowledge, only a few studies (Cauchard, Cane, & Weger, 2012; Hodgetts, Vachon, & Tremblay, 2014), have looked at the combined effects of background speech and task interruptions. However, those studies did not investigate the combined effects on an applied office-related task as writing. Therefore, in Paper III the goal was to investigate the combined effects of background speech and task interruptions on a writing task.

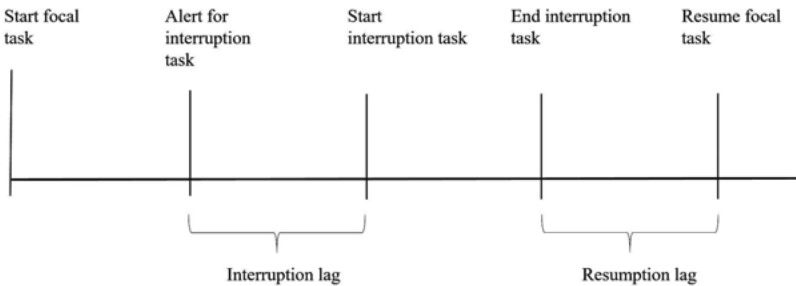


Figure 2. The timeline for an interruption (Trafton & Monk, 2007)

Sound source location

A third factor—in addition to speech intelligibility and interruption—that is relevant to consider for a full understanding of how background speech disrupts performance of people working in office environments, is the location of the sound source. The spatial position of people talking in the background and the number of people talking simultaneously in open offices can vary. Both relative distances and degrees between the background speakers and the ‘receiver’ can vary from minute to minute and from day to day. Despite this reality, not many studies have taken the position of the sound source into account and most studies present the background sound via headphones or loudspeakers from a fixed point in the lab without manipulating their position.

In some of the few studies that have manipulated sound source location, Buchner, Bell, Rothermund and Wentura (2008) and Spence, Ranson and Driver (2000) found that location of the sound source can influence the individual’s reaction to noise. These results are in line with the model of cross-modal attention (Driver & Spence, 1998). According to this model, there are spatial links in attention between different modalities. This means, that it is easier for people to shift attention between information from two different modalities (e.g. visual information and auditory information) when the sources are located in a common point in space compared to when they are located in points with a larger spatial separation (e.g. visual information in front of and auditory information behind the individual) (Driver & Spence, 1998; Spence & Driver, 1996). This model suggests that when the spatial separation between a task-irrelevant and a task-relevant stream of information increases, the task-irrelevant stream of information should become less distracting, even when the

streams of information are in different sensory modalities (e.g. visual vs. auditory) (Spence et al., 2000). Buchner et al. (2008) based their experiment on this model. They presented visual to-be-recalled information in front of the individual and found that task-irrelevant sound coming from the front of the individual, the same location as the visually oriented location, was more distracting to recall compared to sound coming from behind.

Another explanation of the possible differences in the magnitude of sound distraction depending on sound source location is the differences between the two brain hemispheres (Hadlington, Bridges, & Beaman, 2006; Hadlington, Bridges, & Darby, 2004). As the left hemisphere in the brain is more involved in processing of language and as the contralateral connections in the brain are stronger than the ipsilateral connections, speech presented to the right ear is dominantly processed in the left hemisphere compared to speech presented to the left ear (Beaman, Bridges, & Scott, 2007). Consequently, unattended task-irrelevant speech might be more distracting when presented to the right ear compared to the left. This right-ear disadvantage was found in Sörqvist, Marsh, and Jahncke (2010), but only when participants had to recall words in free order. However, there seems to be no right-ear disadvantage for performance on a writing task (Keus van de Poll & Sörqvist, 2013).

When voices are spread out over the room while talking simultaneously, the disruptive effect on serial recall performance is larger compared to when all voices are played simultaneously through the same loudspeakers (Jones & Macken, 1995). This indicates an ability to stream individual speech signals for individual analysis because of their different spatial locations. Multiple voices should mask each other, but this effect appears to be small when the voices have different source locations; multiple voices do not reduce, to any important degree, the changes in acoustical variability of the sound that reaches the ear. Paper IV investigated whether sound source location modulates the disruptive effect of speech on writing. As sound presented to the left vs right ear in earlier experiments did not lead to different effect magnitudes, at least in the context of writing, in Paper IV we choose to focus on a front-behind manipulation in line with the model of cross-modal attention.

Individual differences

In addition to speech intelligibility, task interruptions and sound source location, individual differences in working memory capacity, noise sensitivity and inattention may also play a role in how noise influences performance and well-being.

Working memory capacity

As mentioned before, working memory is, according to Baddeley (2000), a limited capacity system for both temporary storage and processing of information. From this perspective, larger working memory capacity should, reasonably, be related to more space for storage and processing, which, consequently, will favor performance. On the other hand, Engle (2002) proposes that working memory capacity has very little to do with memory *per se*. It is instead

viewed as the ability to use attention and suppress information. Higher working memory capacity means greater capability to use attention and, thus, also greater ability to avoid distraction. Both views of working memory can inform our understanding of the effects of speech on writing. Working memory plays a central role in the execution of the non-automated processes of writing, like reasoning, formulation, decision making and monitoring (Hayes, 1996; Kellogg, 1996). The central executive and phonological loop, as described in Baddeley's working memory model, should play an especially important role in these processes. Research on relationships between working memory and writing performance have for example shown that older adults show poorer working memory task performance and write less complex texts compared to younger adults or children (Bourdin & Fayol, 1994; Hoskyn & Swanson, 2003; McCutchen, Covill, Hoyne, & Mildes, 1994). Moreover, low working memory capacity is associated with low writing complexity (Hoskyn & Swanson, 2003). Hence, individual differences in working memory capacity can predict differences in writing performance.

Besides the role for working memory in writing, individual differences in working memory capacity play also a role for the effect of background noise on cognitive performance (see for reviews, Sörqvist & Marsh, 2015; Sörqvist & Rönnerberg, 2014). For instance, individual differences in working memory capacity can predict differences in susceptibility to the effects of speech on prose memory (Sörqvist, Ljungberg, & Ljung, 2010) and reading comprehension (Sörqvist, Halin, & Hygge, 2010). Higher working memory capacity is related to a lower susceptibility to distraction. As working memory plays a role in both performance on writing and in the susceptibility to the effects of speech on different speech-related cognitive tasks, it is reasonable that individual differences in working memory capacity can predict individual differences in susceptibility to the effects of speech on writing performance. Individuals with high working memory capacity should be better in using attention to avoid distraction by background speech and be better in orienting attention to the writing task and therefore perform better compared to individuals with low capacity.

Inattention

Sustained attention and the capability to avoid distractors are impaired for individuals with low working memory capacity compared to individuals with high capacity. This is in line with Engle's (2002) view of working memory capacity. Inattention and distractibility are typical symptoms of attentional disorders like ADHD (DSM-IV-TR, 2000; see Spencer, Biederman, & Mick, 2007, for an overview). This makes it reasonable to think that individuals with ADHD or non-diagnosed individuals with attentional difficulties are more sensitive to (auditory) distraction, have lower working memory capacity and lower cognitive performance overall. However, research on this topic has shown mixed results. Several studies have found reduced working memory capacity (Dige, Maahr, & Backenroth-Ohsako, 2008) and increased susceptibility to (auditory) distraction in adults diagnosed with ADHD (Forster, Robertson,

Jennings, Asherson, & Lavie, 2014; Pelletier, Hodgetts, Lafleur, Vincent, & Tremblay, 2016). On the contrary, other studies have shown that moderate background noise can benefit performance for individuals with ADHD or inattentive but non-diagnosed children (Söderlund, Sikström, Loftesnes, & Sonuga-Barke, 2010; Söderlund, Sikström, & Smart, 2007). The Moderate Brain Arousal Model can explain those counterintuitive results. This model is about regulation of the dopamine system and stochastic resonance (Sikström & Söderlund, 2007). Moderate levels of dopamine are beneficial for cognitive performance in general (Goldman-Rakic, Muly, & Williams, 2000). ADHD is associated with a dysfunctional and hypoactive dopamine system (Solanto, 2002). Dopamine response consists of two components, a tonic component and a phasic component. The tonic component is stimulus independent and regulates the stimulus dependent phasic component (Grace, 2001). Stochastic resonance is that a stimulus has to pass a threshold before it can be registered (Moss, Ward, & Sannita, 2004). When a signal is too weak to pass the threshold, added environmental noise interacts with the weak signal and can push it above the threshold. Too little or too much noise can attenuate performance (Moss et al., 2004).

Inattentive individuals have in general low tonic dopamine levels. Consequently, the regulation of the phasic dopamine levels is inefficient. This results in behavioral and cognitive problems. Environmental noise can through stochastic resonance increase cognitive performance for those inattentive individuals by helping inattentive individuals reach a more optimal level of dopamine. The dopamine levels of attentive individuals are already (more or less) optimal so they do not need external noise to perform well (Sikström & Söderlund, 2007). Paper IV investigated whether background noise has beneficial or detrimental effects on performance and perceived workload for inattentive, but non-diagnosed adults.

Noise sensitivity

Individuals differ in subjective noise sensitivity irrespective of differences in working memory capacity or inattention. Noise sensitivity has to do with how vulnerable a person is to noise, or how strongly an individual reacts to noise (Job, 1999). Reactions can be physiological, like changes in heart rate (Stansfeld & Shine, 1993), psychological, like annoyance (Ryu & Jeon, 2011; Van Kamp, Job, Hatfield, Haines, Stellato, & Stansfeld, 2004; Öhrström, Björkman, & Rylander, 1988), or related to life style or activities (Job, 1999). A reasonable expectation could be that noise sensitivity can also modulate cognitive performance in a noisy environment, much like inattention and working memory capacity. High noise sensitive individuals should be more distracted by background noise and consequently have lower performance compared to their less sensitive counterparts. However, research on this topic has found only small correlations or no correlations at all (Belojević, Öhrström, & Rylander, 1992; Smith & Stansfeld, 1986; Waye, et al., 2002; Zimmer, & Ellermeier, 1999). It should be noted though, that no intelligible background speech was used in those studies, and it is therefore still unclear whether noise

sensitivity will moderate the relation between background speech and cognitive performance.

Paper IV in this dissertation investigated whether individual differences in working memory capacity, inattention and noise sensitivity could predict individual differences in susceptibility to the effects of background speech on writing.

The influence of noise on subjective workload and perception of distractions in the work environment

So far, the focus of this dissertation has mostly been on how background speech disrupts cognitive performance, or, more specifically, writing. However, noise can also influence the subjective perception of the acoustical environment in terms of acoustical satisfaction (Veitch, Bradley, Legault, Norcross, & Svec, 2002), perceived disturbance (Schlittmeier & Hellbrück, 2009; Schlittmeier, Hellbrück, Thaden, & Vorländer, 2008) and mental workload (Ebissou et al., 2015).

Highly intelligible speech is perceived as more distracting compared to less intelligible speech and is related to a higher perceived workload on cognitive tasks (Ebissou et al., 2015; Liebl et al., 2012). Therefore, masked speech should be more appreciated and be related to a lower perceived workload for people conducting cognitive tasks compared to ordinary speech. Indeed, this was found in Haapakangas et al. (2011). Despite this, masking sounds, like continuous noise (Schlittmeier & Hellbrück, 2009) or instrumental and vocal music (Haapakangas et al., 2011), are not all appreciated as masking sounds when compared to quiet.

In some studies, subjective measures as perceived mental workload can detect differences between sound conditions while objective measures of performance cannot (Haka et al., 2009; Schlittmeier et al., 2008). Schlittmeier et al. (2008) explains this with reactive effort enhancement. People try to compensate for the decreased performance in noisy environments by concentrating harder but consequently, they can perceive the environment as more demanding which is mirrored in their perceived mental workload.

In line with the results in Haapakangas et al. (2011), Haka et al. (2009), and Schlittmeier et al. (2008), the expectation in Paper IV was that individuals should perceive the background sound environment as more distracting with highly intelligible speech than with less intelligible speech in the background. The expectation was also that sound from the front should be perceived as more distracting and be related to a higher perceived mental workload compared to sounds from behind, in line with the cross-modal theory of attention (Driver & Spence, 1998). In Experiment 1 in Paper II the aim was to find a more appreciated masking sound than broadband noise. We compared broadband noise with water waves and multiple voices, two less artificial sounds than broadband noise. The expectation in Paper III was that workload should be higher for conditions with both interruptions and background speech.

Summary and purpose

Many people have to deal with task-irrelevant background speech in open-plan offices each workday. This task-irrelevant background speech can increase annoyance and perceived workload and decrease performance. The way in which background speech influences those factors depends on the nature of the task. Writing is a relevant and ecologically valid office task but there is a lack of research on how background speech influences writing performance. In this dissertation, I investigated how background speech, especially speech intelligibility, influences the writing process and subjective perceptions like mental workload and acoustic satisfaction. Other factors that may modulate the way in which background speech influences workload and performance is individual differences in working memory capacity, inattention and noise sensitivity. Lower working memory capacity is related to a greater susceptibility to the effects of noise on cognitive performance. Contradictory results have been found for inattention, as background sounds led to decreased performance in some studies and to increased performance in other studies. Noise sensitivity is especially related to perceived annoyance but even some relations with performance have been found. In the current dissertation, I investigated whether working memory capacity, inattention and noise sensitivity can influence the impact that background speech can have on writing performance and mental workload.

Given the distraction problems that emerge due to background noise, organizations can choose to use masking methods in an attempt to reduce the distracting effects of background speech. However, these methods are not always appreciated. Moreover, it is common that sounds within offices are generated from different locations, and depending on the location relative to the individuals head, these sounds may be more or less distracting. Distracting factors other than background speech, like colleagues asking questions that need an immediate answer, may also have an effect on cognitive performance. Given these factors, I investigated whether there could be other, more effective and appreciated masking sounds, and whether sound-source location and task interruptions combined with background speech, can modulate the way in which background speech influences performance and perceived mental workload.

Summary of the papers

Research questions

Paper I

The aim of this paper was to get a deeper understanding of the role of speech intelligibility of the background speech signal with regard to the effect of task-irrelevant background speech on writing. The research question was: what role does speech intelligibility play in the disruptive effect of task-irrelevant background speech on writing? The hypothesis was that highly intelligible speech should be more disruptive for writing compared to less intelligible speech.

Paper II

In this paper, there were two main aims. The first aim was to find a more effective and appreciated way of masking a single voice than masking by pink noise. To do this, we compared less artificial sounds as water waves and multiple voices with pink noise. The hypothesis in Experiment 1 was that water waves, and especially multiple voices, should be more appreciated and be a more effective masker with regard to its protective effects for performance compared to masking by pink noise.

The aim in Experiment 2 was to study masking by multiple voices in the context of writing. The hypothesis was that writing performance should be better when the number of voices talking simultaneously increased. This, because speech intelligibility will decrease when more people are talking simultaneously.

Paper III

As both interruptions caused by background speech and interruptions caused by task-shifting shift the locus of attention, the aim of this paper was to investigate the combined effects of background speech and task shifting on writing performance and perceived mental workload. The hypothesis was that the presence of background speech should prolong the time it takes to reach the same writing speed after an interrupted task as before the interruption. Moreover, the presence of background speech should increase perceived mental workload compared to when no background speech was present. In Experiment 1, we tested the hypothesis in a setting with monologues and quiet. In Experiment 2, the same hypothesis was tested but we chose a more ecologically valid setting, by comparing a quiet condition to background speech comprising dialogues and halfalogues.

Paper IV

In this paper, the aim was, first, to investigate whether sound source location plays a role for disruption of writing, and whether it influences perceived mental workload. Second, the aim was to find out whether number of voices talking simultaneously (i.e. 1 voice vs 7 voices) interacts with sound source location. Moreover, we investigated the role for individual differences in working memory capacity, inattention and noise sensitivity.

A hypothesis was that sound with a source at the front of the individual should be more distracting and relate to higher perceived mental workload compared with sound with a source located behind, and that one voice should be more distracting and relate to higher perceived mental workload compared to seven voices. Moreover, another hypothesis was that people with high working memory capacity and/or low inattention and/or low noise sensitivity should be less distracted and therefore perform better on a writing task compared to people with low working memory capacity and/or high inattention and/or high noise sensitivity.

Method

Materials

See Table 1 for an overview of the dependent and independent variables used in the papers in this thesis.

Background sounds

The background sound signals comprised task-irrelevant background speech in Swedish for all four papers. The manipulations of the background speech were different between the papers. In Paper I, background speech and pink noise were mixed in different proportions to create five different Speech Transmission Index values (i.e. $STI = 0.08; 0.23; 0.34; 0.50; 0.71$). The sound files contained recordings of a male actor reading different stories about frogs and fishes as weather prophets, poetry, choir song, meditation and wheat dwarf disease. The files were played back with a sound pressure level of approximately 60 dBA.

In Experiment 1 in Paper III, the sound files about choir song and frogs and fishes as weather prophets were used, but they were not masked. In Experiment 2 in Paper III, a telephone conversation about everyday life between a man and a woman was recorded. For the dialogues, the complete conversation was audible. For the halfalogue, we erased the male part of the conversation, simulating a telephone conversation where only one part of the conversation was audible. The sound pressure level of the sound files was 68 dBA.

In Experiment 1 in Paper II, we created five conditions. The sound in one condition comprised the voice from a single person reading sentences. In one condition, there was quiet. In the other three conditions, the single voice was masked with pink noise, the sound of water waves and multiple voices, respectively. For the ‘water waves’ condition, the single voice was masked by two recordings that were mixed together. The first recording was the sound of water

waves crushing against land and the second recording was the sound of ocean wind. For the ‘pink noise’ condition, only pink noise was used to mask the single voice. The ‘multiple voices’ condition in Experiment 1 comprised nine persons talking simultaneously about different topics and by multiplying this file of nine simultaneous voices by five, so, in total, it sounded like 45 people were talking simultaneously. The single voice sound was played through a loudspeaker standing between the two workstations and the masking sounds were played through two loudspeakers hanging in the ceiling above the used workstations. To create the ‘multiple voices’ conditions in the second experiment, three, five and seven voices from female audiobook narrators respectively were mixed. These files were played through headphones.

For Paper IV, two of the sound files from Paper II (Experiment 2) were used, i.e. the one voice and the seven voice mix. Sounds were played through loudspeakers. One loudspeaker stood in front of the participant with a distance of 150 cm and one loudspeaker was located behind the participant at the same distance measured from the head of the participant.

Writing task

The writing task was the core task in all four papers, as the main goal of this dissertation was to investigate the impact of background speech on word-processed writing. In all experiments except for Experiment 1 in Paper II, participants were asked to write stories based on different keywords, like different nature scenes (i.e. forest, city, ocean, field, mountain, desert) or different fairy tale figures (i.e. Pippi Longstocking, Snow White, Winnie the Pooh, Three Small Pigs, Emil, Ronia the Robber’s Daughter, Little Red Riding Hood). The instructions were to write a story about the keyword but not to describe the keyword in itself. Participants were allowed to write anything as long as it was about the keyword. To avoid a trade-off between quality and quantity of the written task, we asked participants to write as fast and correct as they could. Each writing condition was running for 5 minutes. We used the software program ScriptLog to register the writing process. With ScriptLog it is possible to register and replay every press on the keyboard. After data collection it is possible to extract the variables of interest, e.g., writing fluency, number of pauses > 5 seconds and writing speed. Writing fluency is defined as the total amount of characters in the final edited text plus the total number of deletions made during the writing period. Pauses longer than 5 seconds were chosen to make results comparable to earlier studies (e.g. Ransdell & Gilroy, 2001; Ransdell et al., 2002). We calculated writing speed as the total number of characters typed per second.

Interruption task

In Paper III, the idea was to investigate to what extent background speech can influence the time needed to regain the same writing speed after an interruption as before an interruption. For this purpose, we created a calculation task consisting of eight arithmetic problems, i.e. addition and subtraction problems. Three times during the 5-minute writing period, after 60 seconds of writing, participants had to shift task, from the writing task to the calculation task and

solve as many arithmetic problems as they could for a period of 30 seconds. After that, they had to continue with the writing task for another 60 seconds. See Figure 3 for a timeline of the condition. The arithmetical problems were all composed of numbers above 100 (e.g. $358 + 245$; $631 - 297$) to maintain a relatively constant and high level of difficulty and to minimize the possibility for rehearsal and memorizing of the text written before the interruption.

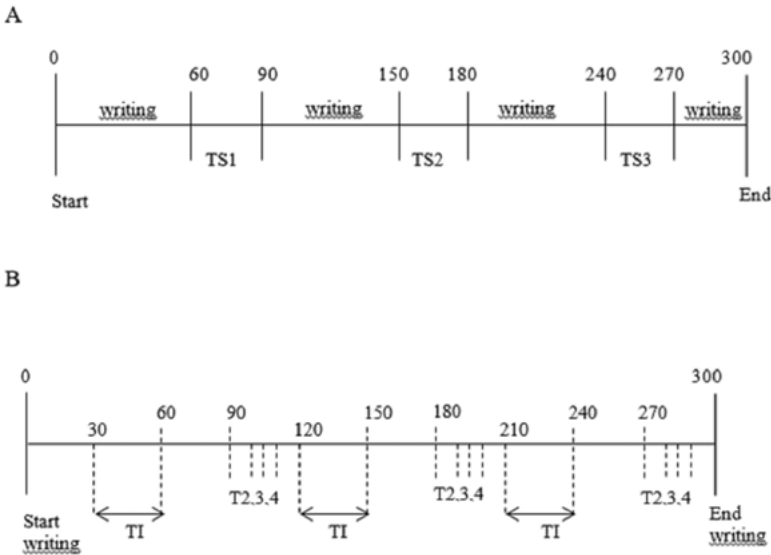


Figure 3. The figure displays the timeline for the experimental conditions, starting at 0 seconds and ending at 300 seconds. In conditions with background sound, the sound was played continuously during the whole period of 300 seconds. Panel A shows the position (in time) for the three task interruptions (TS1, TS2, TS3: Task Shift Interval 1, 2 and 3 respectively) as they were presented in experimental conditions with task interruptions. In experimental conditions without task interruptions, the participants continued writing during these time intervals. Panel B shows the time intervals where writing speed (characters/second) was measured (T1: the last 30 seconds before interruption; T2, 3, 4: the first 10 seconds after the interruption, the next 5 seconds after and the next 5 seconds after that, respectively). Note that the time intervals, at which point writing speed was measured, were the same for all conditions (for those with and those without interruptions, and for those with and those without background sound).

Serial recall task

A well-established method to study distraction by noise is the use of serial short-term memory tasks. In Experiment 1 in Paper II, different to-be-recalled series of digits (i.e. numbers from 1-9) were presented in random sequence. Within one sequence, all digits were presented once. Each digit was presented on a computer screen for 500 ms with an inter-stimulus interval of 300 ms.

Half a second after the presentation of the last digit of the sequence, participants had to recall the digits in correct sequential order. One point was assigned for each digit accurately recalled at the right list position. There were nine different to-be-recalled sequences in each sound condition.

Questionnaire for subjective ratings of sound

In Experiment 1 in Paper II, effects of masked background speech on performance and on subjective ratings about the sound environment were investigated. Questionnaires with statements about the acoustic environment were used to measure acoustic satisfaction and subjective mental workload (Haapakangas et al., 2011; Haka et al., 2009). The questionnaire that measured ‘acoustic satisfaction’ consisted of 11 statements (“the sound environment was pleasant”, “the sound environment was disturbing”, “the sound environment was acceptable”, “the sound environment was loud”, “overall, I was satisfied with the sound environment”, “habituation to the sound environment was easy”, “surprising changes occurred in the sound environment”, “the sound environment often caught my attention”, “I could work uninterrupted during the test” and “I could work effectively during the test”). The three statements that measured ‘subjective workload’ were, “the sound environment impeded my ability to concentrate”, “the sound environment impaired my performance”, and “the task felt difficult”. Each question was scored on a 5-point Likert scale where low scores indicated disagreement with the statement.

The main idea in Paper IV was not to measure the subjective ratings of the sound environment, but only to get an indication about whether participants experienced a certain background speech condition as more distracting compared to another. So in this case, only one question about the distraction of the background sound was asked with a 7-point Likert Scale (“How distracted were you by the acoustical environment?”).

NASA-TLX

In Paper III and IV, we measured subjective mental workload by using the NASA-TLX (Task Load Index) (Hart & Staveland, 1988). This questionnaire was originally developed for application in aviation, but the last 20 years its use has been spread far beyond this subject. Six different rating scales are defined, i.e. mental demand (“How mentally demanding was the task?”), physical demand (“How physically demanding was the task?”), temporal demand (“How hurried or rushed was the pace of the task?”), effort (“How hard did you have to work to accomplish your level of performance?”), performance (“How successful were you in accomplishing what you were asked to?”) and frustration level (“How insecure, discouraged, irritated, stressed and annoyed were you?”). Except for the physical demand scale, all other scales were judged relevant for the purpose of Paper III and IV, where the impact of background speech on perceived mental workload was explored. The five scales were translated to Swedish and re-worded to fit the concerning studies better (How mentally demanding was the task?; How much time pressure did you experience?; How satisfied are you with your written text?; How difficult was it for

you to write the text you desired?; How insecure, stressed and/or irritated were you during the writing task?). Answers were given on 7-point Likert Scales. Workload Index scores were calculated by taking the average from the five questions.

Working Memory Capacity Test

In Paper IV, the role for working memory capacity was investigated. A well-established test to measure working memory capacity is the Size Comparison Span test (SICSPAN) (Sörqvist, Ljungberg et al., 2010). In the SICSPAN test, participants have to make size comparisons of pairs of objects and recall to-be-remembered words that are presented after the size comparison. In the first step, a size-comparison pair of objects is presented on a computer screen (e.g. is PIANO bigger than GUITAR?). The participant has to respond to this question, as quickly as possible, with 'yes' or 'no', by pressing a key. Then, a to-be-remembered word is presented (e.g. SAXOPHONE) for one second for later recall. After that, a new pair of objects is presented with a new to-be-remembered word. This cycle is repeated until the list with size-comparison objects and to-be-remembered words is finished. When the list is finished the subject has to recall all the to-be-remembered words in the order of presentation. The first list contains two size-comparison pairs and two to-be-remembered words. List-length increases with one size-comparison pair and one to-be-remembered word for each list thereafter. The maximum list length is six pairs and to-be-remembered words. In total, there are 10 lists. All objects and to-be-remembered words within one list come from the same semantic category and all objects and to-be-remembered words are only presented once. Each list is taken from a unique semantic category.

ADHD Self Rating Scale

The second individual difference variable investigated in Paper IV was inattention. To measure inattention participants filled in part A of the ADHD self-rating Scale (ASRS). The ASRS is a symptom checklist developed by the World Health Organization (2003) as a helping tool in screening for ADHD. It consists of two parts, part A, representing symptoms of inattention, and part B, representing symptoms of hyperactivity/impulsivity. Each part is composed of nine statements with 5-point Likert answering scales where 0 represents "never" and 4 represents "very often". The statements are consistent with the criteria for ADHD according to the DSM-IV-TR (2000). Total scores are calculated for each part separately by adding the scores for the nine statements. If the score for either part A or B is 0-16, it is very unlikely that the individual has ADHD, if the score is 17-23 it is likely and if the score is 24 or higher it is very likely that the individual has ADHD.

Noise Sensitivity Scale

The third individual difference variable investigated in Paper IV was noise sensitivity. A short and Swedish version of the original Noise Sensitivity Scale (Weinstein, 1978) was used. This Swedish version was developed by Nordin,

Palmquist and Claeson (2013) and consists of 11 questions/statements about noise (e.g. I would not mind living on a noisy street if the apartment I had was nice; I am more aware of noise than I used to be; At movies, whispering and crinkling candy wrappers disturb me; I am easily awakened by noise). Answers were given on a 6-point Likert scale ranging from ‘do absolutely agree’ to ‘do absolutely not agree’.

Table 1. The independent measures, dependent measures and predictor variables used in the four papers in this dissertation.

Independent variables	<i>Paper I</i>	<i>Paper II</i>	<i>Paper III</i>	<i>Paper IV</i>
Background speech	x	x	x	x
Sound source location				x
Task interruptions			x	
Dependent variables:				
Writing fluency	x	x		x
Writing speed			x	
Number of pauses > 5sec	x			x
Perceived mental workload		x	x	x
Serial recall score		x		
Perceived acoustical environment		x		
Perceived background sound distraction				x
Predictor variables				
Working memory capacity				x
Inattention				x
Noise sensitivity				x

Design and procedure

In all experiments except for Experiment 1 in Paper II university students participated. For Experiment 1 in Paper II employees of a consultancy firm in Stockholm were recruited. We informed all participants in all experiments that their results would not be seen by anyone in lack of permission, about their right to abort and leave the experiment whenever they wanted without giving reason and that their participation was voluntary. Within-subject designs were used in all experiments. Participants were tested alone in quiet rooms in front of a computer except for Experiment 1 in Paper II where two participants were tested at a time in an open-plan office with ten workstations. Participants wore headphones during the whole experiment in all experiments except for the experiment in Paper IV and Experiment 1 in Paper II where background sound came from loudspeakers in the room. In all experiments, participants were asked to try to ignore the background sounds. In Paper I, participants only completed the writing task. The task started with one trial condition of one minute and was followed by the five different sound conditions. In Experiment

1 of Paper II participants started with the serial recall task for the five sound conditions. After the serial recall task was done, participants filled in the questionnaire for subjective ratings of the sound. The procedure for Experiment 2 in Paper II was similar to the procedure in Paper I. In Paper III, for each condition, the five-minute writing period was divided in three cycles of 60 seconds for writing followed by 30 seconds for the interruption task. The last 30 seconds of the five-minute period consisted of writing time (Figure 3). After each condition, the participants filled in the NASA-TLX. In Paper IV, participants started with the working memory capacity task in quiet, followed by the writing task for the five different sound conditions. When a condition was finished, they filled in the NASA-TLX questionnaire and the question about background sound distraction. After the writing task was finished, participants filled in part A of the ASRS. For all experiments, onset and offset of the sounds were synchronized with the onset of the task and the order of the sound conditions was counterbalanced by using Latin Square Designs.

Results

Paper I

The aim of Paper I was to investigate the relationship between Speech Transmission Index of task-irrelevant background speech and writing performance. The main result in Figure 4 showed a decrease in writing performance, measured in writing fluency, for an increasing Speech Transmission Index. An important finding was that the largest decrease in performance occurred between STI 0.23 and 0.34; that is, at relatively low STI values. This performance drop occurred earlier than Hongisto (2005; Figure 1) predicted. When STI is between 0.23 and 0.34 speech intelligibility is still low. It is hard to understand complete sentences or conversations especially when the speech signal is unattended. The finding that performance drops at such low values of speech intelligibility underlines the sensitivity of writing to background speech. The results for the total number of pauses > 5 seconds in Figure 5 were in line with the results for writing fluency as the number of pauses increased for increasing STI with the largest increase of pauses between STI 0.23 and 0.34.

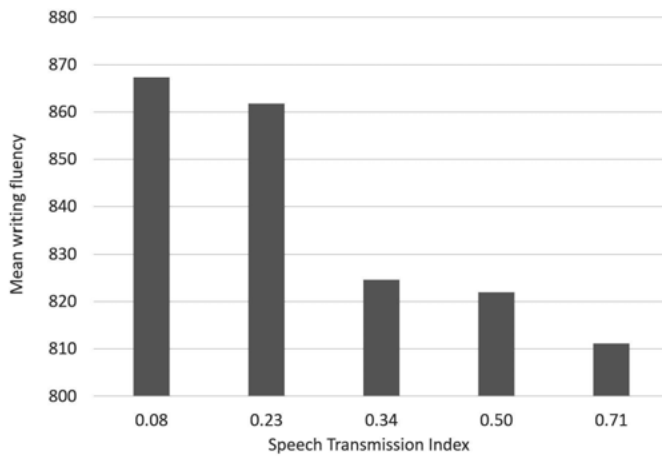


Figure 4. The relation between STI and mean writing fluency. Note that a higher value of STI corresponds to higher speech intelligibility in the background speech signal.

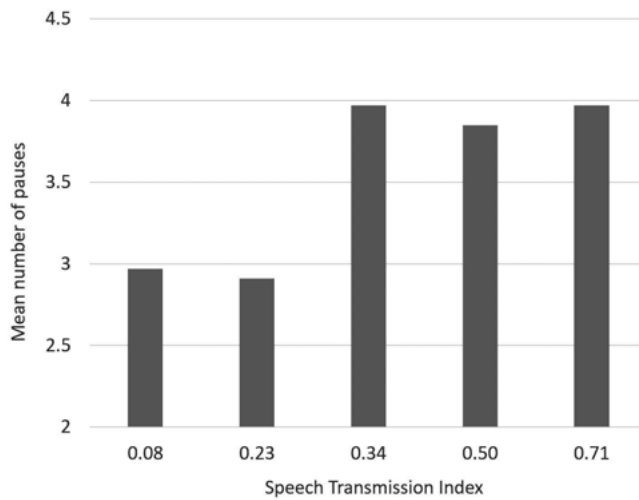


Figure 5. The relation between number of pauses > 5 seconds and STI. Note that a higher STI means a higher amount of speech intelligibility in the background speech signal.

Paper II

In Experiment 1 the goal was to find a more appreciated and effective method of masking. Figure 6 shows that performance was best when a single voice was masked by other voices and when it was masked by water waves. In those conditions, performance was as good as in quiet. Figure 7 shows that lowest workload and highest appreciation was rated in quiet, followed by a single voice masked by multiple voices and a single voice masked by water waves. Altogether, the best alternative masking method was masking with multiple voices.

In Experiment 2 this masking method was investigated in more detail by manipulating the number of voices talking simultaneously. Figure 8 shows that performance increased when the number of voices increased, or in other words, when speech intelligibility decreased.

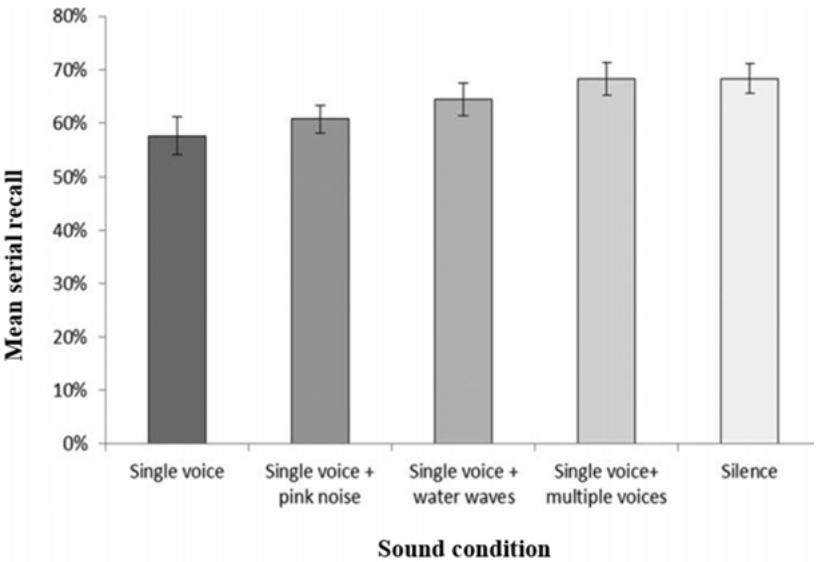


Figure 6. The mean score of correct answers in percent on the serial recall task for the different sound conditions.

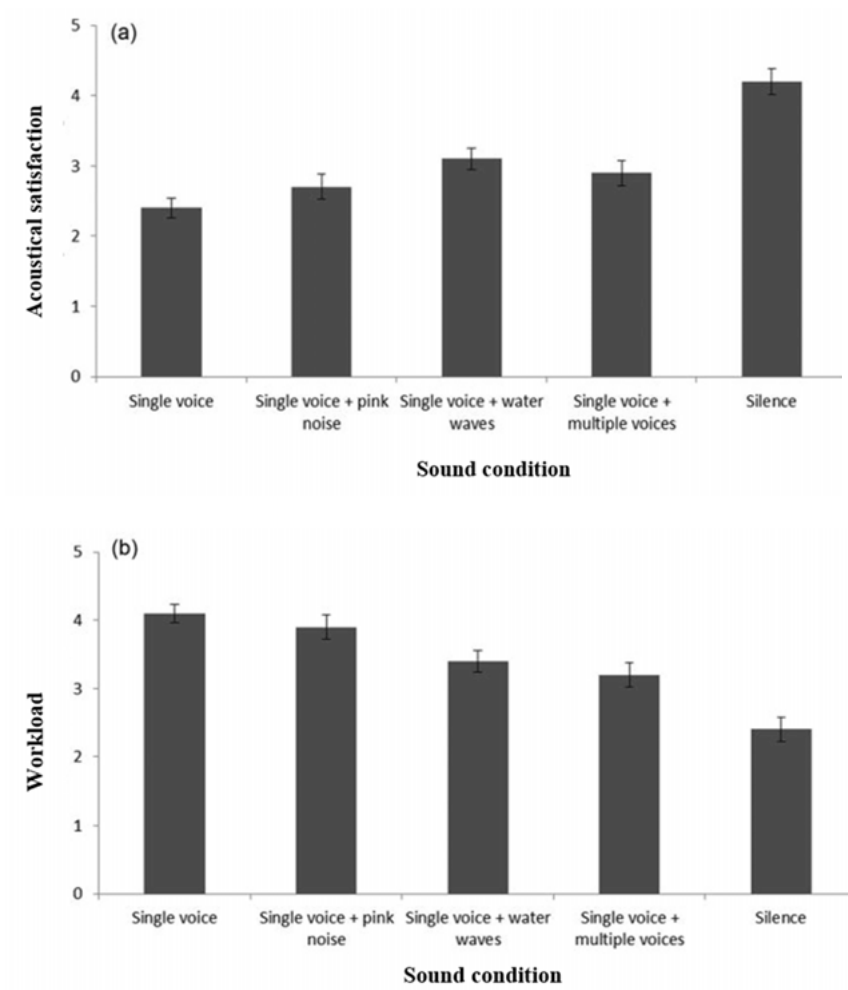


Figure 7. Panel A: subjective ratings about acoustical satisfaction in the different sound conditions. Panel B: subjective ratings about workload in the different sound conditions.

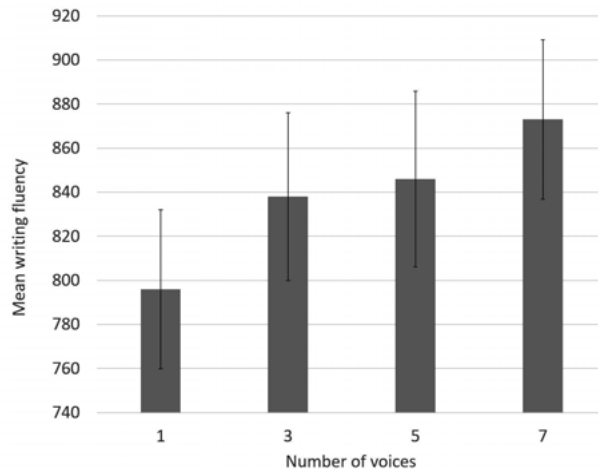


Figure 8. Mean writing fluency for 1, 3, 5 and 7 multiple voices.

Paper III

The aim of Paper III was to investigate whether background speech adds to the time it takes to reach the same writing speed after an interruption as before. Results for Experiment 1 showed that after an interruption, writing speed was back at the same level as before the interruption after about 10-15 seconds. We found no interaction between background sound and interruption, which was against the expectations. Figure 9 shows the results for analyses with only the two intervals 'last 30 seconds before the interruption' and '10 seconds after interruption'. Participants tended to increase writing speed after they had been writing for a while, but this occurred only when they were writing in quiet. Background speech made it hard to reach those higher writing speed levels. The subjective ratings on mental workload showed that perceived mental workload was lowest in the quiet condition and highest in the condition with background speech and task interruptions. The results in Experiment 2 were in line with the results found in Experiment 1. It took participants 10-15 seconds to reach the same writing speed as before the interruption. Figure 10 shows that writing speed before the interruption was lower when background speech consisted of a dialogue than when it consisted of a halfalogue or when it was quiet. There were no differences in writing speed between conditions with quiet versus halfalogues. This indicates that background speech consisting of dialogues is more disruptive compared to background speech consisting of halfalogues. Subjective ratings in Experiment 2 showed that perceived mental workload was lowest in the quiet condition without interruptions and highest in the condition with interruptions and dialogue as background sound. The results confirm the findings that highly intelligible speech or speech containing more semantic information is more disruptive compared to less intelligible speech or speech with less semantic content.

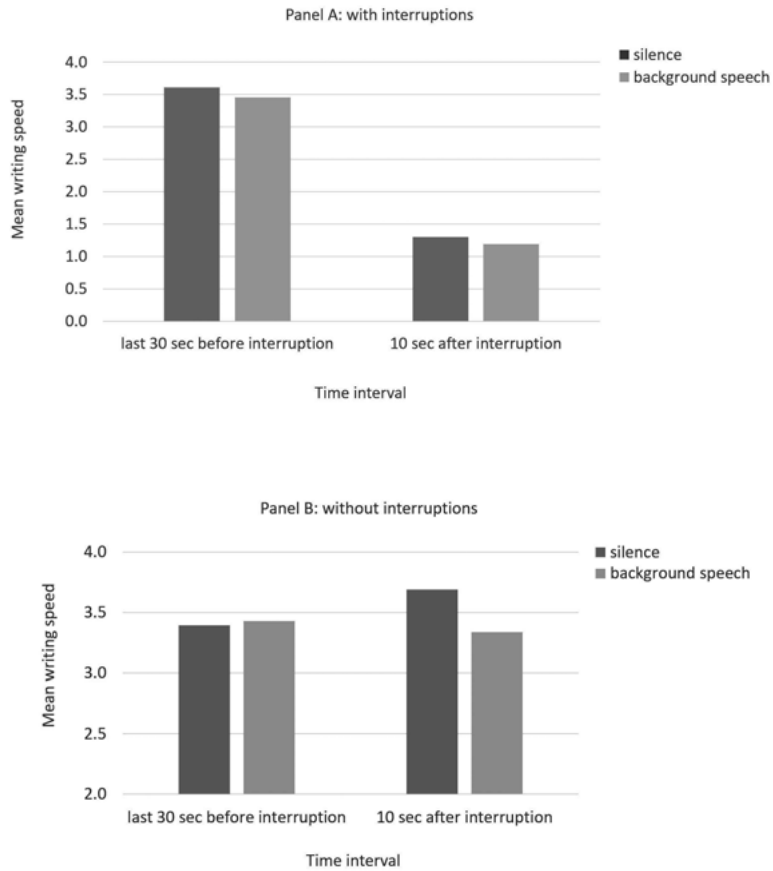


Figure 9. Mean writing speed (characters/sec) for conditions with and without background sound at two different time intervals; last 30 seconds before interruption; 10 seconds after interruption, and for conditions with interruptions (panel A) and without interruptions (panel B). Note that the Y-axis is truncated.

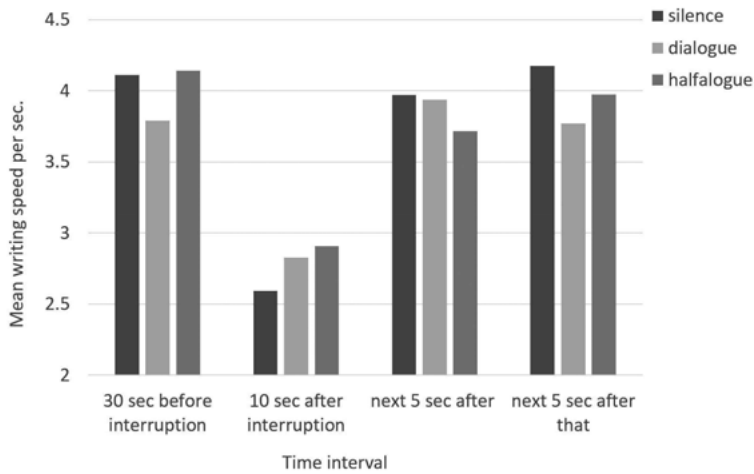


Figure 10. Mean writing speed (characters/sec) for conditions with dialogue and halfalogue as background sound and in quiet at four different time intervals: last 30 seconds before interruption; 10 seconds after interruption; the next 5 seconds after; and the next 5 seconds after that. Conditions with and without interruptions are collapsed. Note that the Y-axis is truncated.

Paper IV

The idea with Paper IV was to investigate the role for sound source location in the relation between background speech and writing, to explore whether there was an interaction with number of voices and whether individual differences like inattention, working memory capacity and noise sensitivity play a role in the disruption of writing by noise. A main effect of voices was found. Writing fluency was lower and number of pauses > 5 sec was higher when background speech consisted of one voice compared to background speech consisting of seven voices. These results were in line with the results from Paper I and II and indicate that highly intelligible speech is more disruptive compared to less intelligible speech. Writing fluency was lowest and number of pauses > 5 sec highest when one voice was located at the front and writing fluency was highest when seven voices were located behind the individual. Number of pauses was lowest in quiet.

Figures 11 and 12 show that writing fluency was lower and number of pauses higher when background speech consisted of one voice compared to background speech consisting of seven voices, for high inattentive individuals. Moreover, high inattentive individuals performed better (i.e. had higher writing fluency and lower number of pauses > 5sec) compared to low inattentive individuals when background speech consisting of seven voices was located behind the individual.

High noise sensitive individuals needed more pauses in conditions with one voice compared to conditions with seven voices. No clear effect of sound source location was found except for an effect on the subjective experience of background sound distraction. Sound from the front was experienced as more distracting compared to sound from behind, which is in line with the hypothesis. No effects were found for working memory capacity.

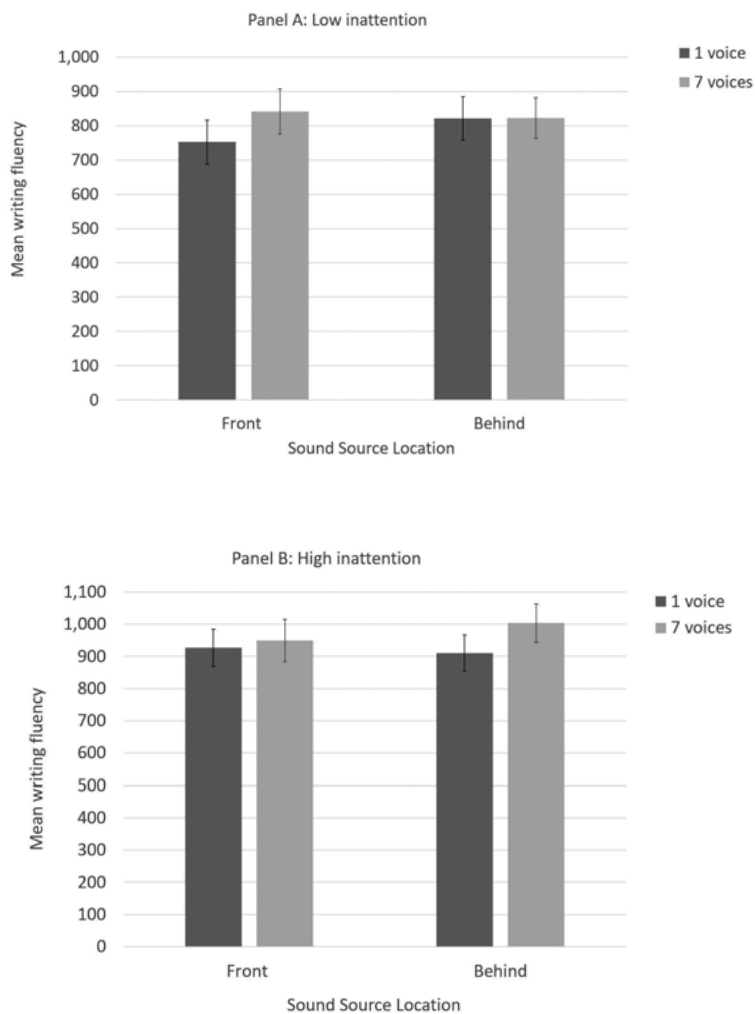


Figure 11. Panel A: Interaction between voices and location for low inattentive individuals with mean writing fluency as the dependent variable. Panel B: Interaction between voices and location for high inattentive individuals with mean writing fluency as the dependent variable. Error bars represent standard error of means.

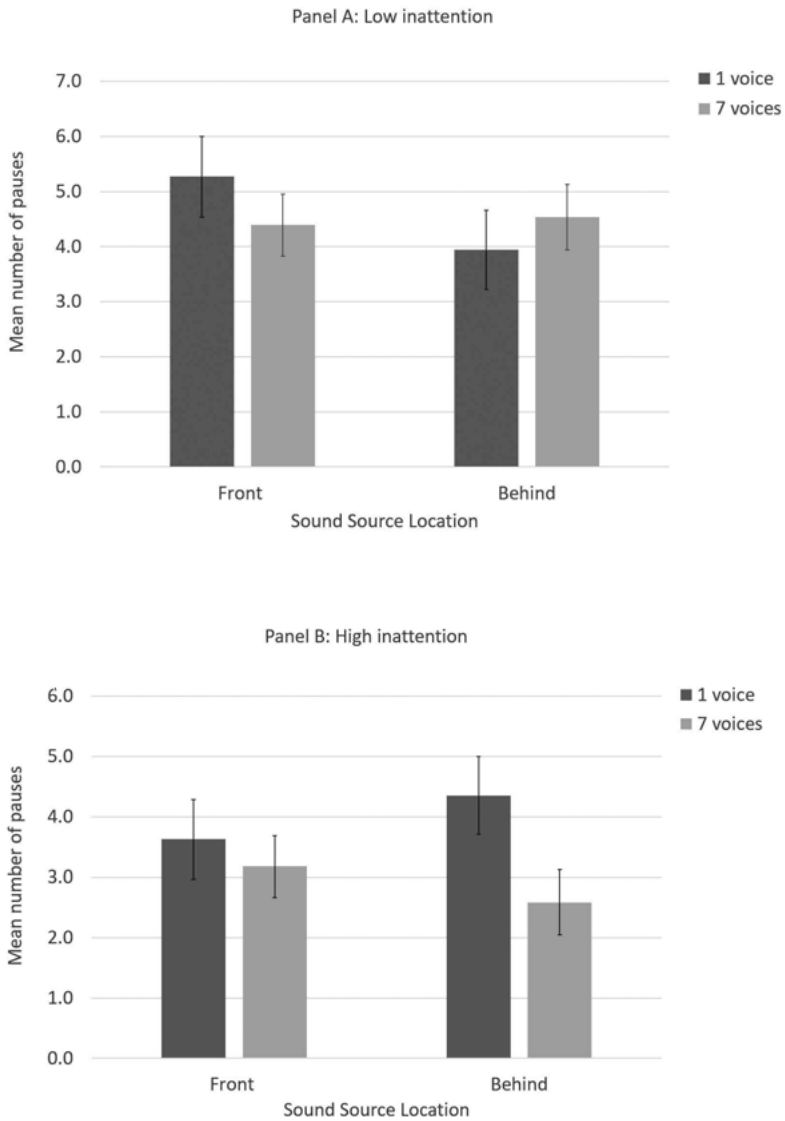


Figure 12. Panel A: Interaction between voices and location for low inattentive individuals with mean number of pauses > 5 seconds as the dependent variable. Error bars represent standard error of means. Panel B: Interaction between voices and location for high inattentive individuals with mean number of pauses > 5 seconds as the dependent variable. Error bars represent standard error of means.

Discussion

Summary of results

The focus of this dissertation was to explore how background speech disrupts writing performance. The main result is that even speech with relatively low intelligibility can disrupt writing. We found support for the finding that writing is sensitive to background speech in all four papers, as writing performance increased when intelligibility or the amount of semantic information in the background speech signal decreased. The results therefore underline the importance for reduced speech intelligibility in environments where writing tasks are executed. The use of multiple voices as a masking method is effective in reducing speech intelligibility but acoustical satisfaction and perceived workload are still most optimal in quiet (Paper II). In Paper III, we found that background speech did not add to the effect of interruptions on the time needed to regain the same writing speed (i.e. as before the interruption) after an interruption of another task. On the other side, subjective measures did show that the combination of background speech and task interruptions was related to a higher perceived mental workload compared to the presence of only one of those factors, or quiet. Self-reports showed an effect of sound source location indicating that speech located in front of the individual is perceived as more distracting compared to speech located behind the individual (Paper IV). High inattentive individuals wrote more than low inattentive individuals did when background speech containing seven simultaneous talkers was located behind them (Paper IV) and high noise-sensitive individuals needed more pauses when background speech consisted of one voice compared to background speech consisting of seven voices (Paper IV). In the following sections, I discuss the results from the different papers in more detail.

The sensitivity of writing to background speech

An important finding in Paper I is that writing performance is impaired by speech that is relatively unintelligible, as the largest drop of performance occurred between STI 0.23 and 0.34, which has also been indicated with other tasks earlier (Jahncke et al. 2013). This result shows the relatively high sensitivity of writing to the intelligibility of background speech. This conclusion was further supported by the results in Paper II, as three voices talking simultaneously were more disruptive compared to seven voices talking simultaneously, and by the results of Paper IV as one single talker was more disruptive compared to seven simultaneous talkers. An explanation of the disruption of writing by background speech, which could explain why less intelligible speech is less disruptive, is that the semantical processes that are involved in the automatic analysis of the background speech interfere with similar processes needed for the writing task, which is in line with the theory of interference-by-process (Macken et al., 1999). Attentional capture can explain the variability in number of pauses, as a more intelligible speech signal will contain

more deviant, relevant or otherwise distracting information, leading to a direction of attention to the background speech instead of to the writing task. Consequently, pauses in the writing task increases.

The finding in Experiment 2 in Paper II, that writing fluency decreased as a function of the background speech's intelligibility, even though the noise level of the background speech increased as intelligibility decreased, indicates that speech intelligibility was a more decisive factor for performance than sound pressure level. If sound level would be the decisive factor, writing fluency should have decreased for increasing sound pressure levels, but this was not the case, which is in line with results of Colle (1980), Ellermeier and Hellbrück (1998), and Jones et al. (1990).

In Paper III, intelligibility of the background speech was not manipulated, as all speech signals were highly intelligible. It was rather the amount of semantic information in the background speech signal that was manipulated as halfalogues contains less semantic information than dialogues, and quiet does not contain any semantic information at all. The results here showed that dialogues and monologues were more disruptive compared to halfalogues and quiet. Moreover, individuals reached a higher mean writing speed level in the quiet conditions compared to the conditions with background speech.

Dialogues in Paper III were more disruptive compared to halfalogues. This result goes against results found by Norman and Bennett (2014), Emberson et al. (2010), and Galván et al. (2013) as they found that halfalogues were more distracting because of, for instance, the unpredictability of the halfalogues and the higher need to listen to predict the other half of the conversation. On the other side, the results from Paper III are in line with the theory of interference-by-process, as dialogues contain more semantic information compared to halfalogues and therefore are dialogues more disruptive than halfalogues.

The subjective data showed that workload was higher for both dialogues and halfalogues compared to quiet. There was no distinction between halfalogues and dialogues in the subjective data. One interpretation of this result is that interference between processes is a stronger mechanism compared to the need-to-listen or the unpredictability of the sound, when measured in performance. On the other hand, the subjective data cannot support this interpretation, as perceived workload did not significantly differ between halfalogues and dialogues. However, the results support the earlier findings that writing is sensitive to background speech and that performance seems to be best in quiet.

To mask or not to mask

The conclusion drawn in Paper I was that background speech intelligibility should be very low, preferably below an STI of 0.23, to avoid performance loss in writing. As masking is a way to reduce speech intelligibility and as organizations use broadband noise (e.g. pink noise) as a masking sound, which is not always the most preferred way of masking according to workers (Schlittmeier & Hellbrück, 2009), the focus of Experiment 1 in Paper II was to explore the effectiveness and appreciation of different maskers to find an al-

ternative to pink noise. Experiment 1 in Paper II showed that masking by multiple voices was most effective as performance was not different from performance in quiet. Performance was worst when one single voice without masking was present. However, subjective ratings showed no differences in acoustic satisfaction for multiple voices compared to pink noise. On the contrary, perceived mental workload was lower for multiple voices compared to pink noise. Nevertheless, it was in the quiet conditions that acoustic satisfaction was highest and perceived mental workload lowest. Conclusively, the results of Paper II indicate that masking by multiple voices is an effective way of masking as it reduces the impairing effects that intelligible background speech (i.e. without masking) has on cognitive performance. However, it should not be seen as the optimal solution for the problem of noise in the open office as it is still less appreciated compared to quiet. Even in the long-term, the continuous exposure to noise might lead to health problems, as some research indicates that people staying in noisy office environments do not habituate to the sound environment (Brennan, Chugh, Kline, 2002; Banbury & Berry, 1997). Rather, although the long-term effects for office noise are unclear, long-term exposure to environmental noise or occupational noise with higher intensity levels (approximately between 60-85 dBA) seem to be associated with health-risks and performance decrements for both adults and children like decreased attention control (Kujala, et al., 2004), increased blood pressure (Lee, Kang, Yaang, Choy, & Lee, 2009), increased stress levels among children (Evans, Bullinger, & Hygge, 1998) and impaired reading among children (Evans & Maxwell, 1997).

The role for task interruptions

Results from both experiments in Paper III confirm the results found in the earlier papers that writing is sensitive to background speech as the speech signals with more semantic information (dialogues and monologues) were more disruptive than signals with less semantic information (halfalogues) or in quiet. However, background speech did not add to the time needed to reach the same writing speed after an interruption as before, which was against the expectations. There are several explanations. First, there might have been a floor effect. The arithmetic task might have been of such high difficulty level that it limited the possibility for rehearsal during the execution of the interruption task and for re-orientation after the interruption finished. This limitation to re-orientation might have decreased writing speed to such a level that background speech was unable to decrease it even further. Second, the re-orientation process could have been of such high cognitive load that it functioned like a shield against distraction, similar to the findings in Halin, Marsh and Sörqvist (2015). They showed that individuals executing a harder test could remember less of an unattended story compared to individuals executing an easier version of the task.

One interpretation of this finding is that a more difficult task makes participants more engaged in the task, and thus, processing of to-be-ignored material is constrained when task engagement is high. The same principle could explain why background speech did not add to the time it took to resume the same

writing speed after an interruption as before. Another possible explanation is in line with the goal activation model (Altmann & Trafton, 2002). During the resumption time, the individual had to re-orientate. This means that the individual had to reactivate goals and sub-goals connected to the writing process. This reactivation and reorientation might have used other cognitive processes than the processes involved in writing and the processes involved in the analysis of the background speech. Therefore, an interference between similar processes might not have occurred and should explain why background speech did not add to the time needed to resume the same writing speed after an interruption as before.

Despite the performance data in Paper III that showed that background speech did not add to the time it took to resume the same writing speed as before the interruption, the subjective measures of perceived mental workload suggested that it did. Perceived workload was higher for conditions with both interruptions and background speech, and lowest for quiet conditions without interruptions. So, differences between the different conditions were detected with subjective measures but not to the same degree with cognitive measures. Such a discrepancy between subjective workload and cognitive performance is typical, and might depend on reactive effort enhancement, according to Schlittmeier et al. (2008). This means that the awareness of the disturbing noise motivates the individual to put more effort in the task, which will lead to enhanced or less impaired performance but increased perceived workload or distraction (Schlittmeier et al., 2008).

Even though background speech did not add to the time it took to resume the same writing speed as before the interruption, it took 10-15 seconds to regain situation awareness and to reach the same writing speed as before the interruption. Moreover, subjective measures showed that perceived mental workload was higher for conditions with task interruptions compared to conditions without task interruptions. Conclusively, the results of Paper I and II underline the importance of quiet in work environments where writing tasks are conducted. The results of Paper III adds to this conclusion by indicating that work environments also should be without other external task interruptions than task-irrelevant background sound.

The role for sound source location

The results in Paper IV only gave some support for the idea that sound located in front of an individual is more distracting compared to sound located behind an individual. The only finding supporting this was the question about perceived sound distraction. When also taking into account that Keus van de Poll and Sörqvist (2013) in their study about the right-ear disadvantage did not find any indications that sound source location matters, it is not presumable that sound source location will play an important role as long as noise is coming from one and the same direction. However, it is important to note that the situation can be different in real open office environments as speech and other disturbing noises not necessarily come from the same direction. It is more re-

alistic that speech and other sources of noise come from different spatial locations in the office and that the locations and the number of people talking simultaneously vary during the day. Jones and Macken (1995) found that six different voices that are spread out over the room still can be streamed individually and that this will attenuate the disturbing effect of when the same six voices were not spread out over the room but were all talking from the same location in the office. A study by Yadav, Kim, Cabrera and De Dear (2017) showed that two and four simultaneous talkers, located at different positions in the room, were more disruptive for performance compared to one talker. Conclusively, in light of the findings by Jones and Macken (1995) and Yadav et al. (2017), it is important to keep in mind that seven voices talking simultaneously only might be less disruptive compared to one talking person when the different voices are coming from the same location (as when the speech signal is created to use as a mask for other background speech). The effects might not be the same in a real office where background speech is coming from different locations. As long as the 'receiver' can stream the different conversations separately, it is not certain that seven simultaneously speakers still can reduce the impairment of performance caused by noise.

The role for individual differences

Paper IV did not support the idea that working memory capacity can modulate the relation between background speech and writing performance. One possible explanation is that people with lower working memory capacity, those who were expected to be more distracted by background speech, can compensate for the distraction of noise by concentrating harder in line with reactive effort enhancement (Schlittmeier et al., 2008) described earlier. Because of the increase in concentration, we should expect individuals with lower working memory capacity to perceive a higher mental workload compared to those with higher working memory capacity. We did not find this relation in the papers included in this dissertation. However, even if people with lower working memory capacity can protect themselves from background speech distraction by concentrating harder, it is not plausible that this should hold over a longer period. It is plausible that those individuals will become mentally exhausted after a while because of the increased effort. Future research is needed to investigate more on those long-term effects of background speech on writing and the role for working memory capacity.

High inattentive individuals had higher writing fluency for seven voices compared to one voice. High noise sensitive individuals needed more pauses > 5 seconds for conditions with one voice compared to conditions with seven voices. High inattentive individuals had higher writing fluency when seven voices were coming from behind compared to their attentive counterparts. This result is in line with the Moderate Brain Arousal model (Sikström & Söderlund, 2007) that suggests that inattentive individuals can profit from moderate background noise, as this should help to regulate the dopamine levels. However, future research has to investigate further whether this conclusion can be strengthened or not.

Altogether, the data on individual differences indicate that individual differences can modulate how we respond to task-irrelevant background speech, measured by performance on a writing task. Not all people will react to noise in the same way and thus it is important to consider the possibility to adapt workplaces to the personal characteristics of the individual.

Recommendations for noise in the office environment

The findings of the papers included in this dissertation are of relevance for the design of shared workplaces, such as open offices, and for the international acoustic standards concerning these types of offices. The most important result in Paper I was that the largest drop in writing performance occurred between STI 0.23 and 0.34 and attenuated after that. This drop in performance occurred at lower STI values than Hongisto (2005) predicted (i.e. STI 0.50), and is in line with another study which tested a battery of work tasks (Jahncke et al., 2013). The current results indicate that writing is a task that is highly sensitive to background speech, as even low levels of intelligibility can disrupt writing. In our study, only some information could be understood in the speech signal with an STI of 0.34, especially when the speech signal was unattended. This indicates that the recommendations in international standards (e.g. ISO 3382-3) might be too lenient, at least for high-ordered cognitive tasks as writing. Notwithstanding the fact that masking can help to reduce speech intelligibility, it will in practice be hard, if not impossible, to reach STI levels below 0.34 in open-office environments (ISO 3382-3). Instead, organizations need to offer quiet rooms or quiet areas and create rules for how to behave, especially in those quiet zones (e.g. not to talk, turn off ringtones). Employees that have to write can then switch to those quiet zones when needed. The Swedish Work Environment Authority recommends that background sound levels should not exceed 35-40 dB in environments where activities that require concentration are performed (Arbetsmiljöverket 2005:16). This recommendation is though based on sounds from the building, installations and equipment only and take not into account the sounds caused by the activities from the people working in that building. A typical sound level in open offices is around 50 dBA (Venetjoki et al., 2006). As masking will add to the general noise level, it will only make it harder to reach and follow the recommendations about background noise levels.

All four papers in this dissertation give support for the finding that writing performance and perceived mental workload are best in quiet environments or environments with low speech intelligibility. Task interruptions are also perceived to increase mental workload and they delay the writing process, as a certain amount of time is needed after each interruption for reorientation on the task. Masking seems not to be appreciated compared to quiet conditions, though some sounds were effective. Altogether, the findings underline the importance of offering a quiet area without external interruptions, for employees performing writing tasks. Also, the finding that sound source location might play a role and that individual differences can modulate the relation between

background speech and writing fluency indicate that those factors should be taken into consideration when designing workplaces.

Strengths, limitations and future directions

The main aim of this dissertation was to investigate how background speech can impair writing performance. As mentioned before, in the past only a few studies (Ransdell & Gilroy, 2001; Ransdell et al., 2002; Sörqvist et al., 2012) have explored the relationship between background sounds and writing. A strength of the current dissertation is that it has extended the knowledge of the relationship between background speech and writing. This has been done by investigating this relation in a more detailed way and from a more applied perspective by manipulating speech intelligibility of the background speech and taking into account aspects as task interruptions, sound source location and individual differences.

To manipulate speech intelligibility and semantic information in the background speech signal, we made no recordings of real open office noise, instead we used existing files of clear and intelligible background speech recorded in an anechoic chamber. This made it easier to manipulate and mask the speech signals with different sounds. The benefit was increased experimental control. On the other hand, the ecological validity and generalization of the results to open-plan offices are restricted and should therefore be made with care. Future research should explore the effect of ecologically valid background speech signals to get more insight in background speech distraction on writing in real office situations.

We asked our participants to write for a period of 5 minutes. How participants exactly spent this time varied largely, which caused large error variances. The large error variances might explain why we not always found the expected results, for example the absence of modulation of working memory capacity on the disruption of writing by background speech. Another limitation is that the ScriptLog program only can extract data considering quantitative aspects of the writing process and not qualitative aspects about the content of the written texts. Sörqvist et al. (2012) analyzed the number of propositions in the texts, as a way to measure text quality, but they did not find an effect of background sound on the quality of the text. This study indicates that background sound does not influence text quality, but more research is needed before this can be concluded.

In all experiments, writing periods were never longer than five minutes per condition. This means that we only investigated short-term effects of background speech. We do not know how writing fluency will be influenced when background speech is present under longer periods. At last, despite the fact that writing fluency seems to be best in quiet conditions without external interruptions, some people choose to sit in cafés or other ‘noisy’ environments where background speech is the main source of noise. Some people think that they can concentrate and perform better in those environments, without knowing how their performance is actually influenced during noisy conditions. However, a difference with cafés compared to a dedicated workplace in an open-

plan office is that people choose to be there themselves. Research regarding the importance of perceived control suggests that behavior that is self-determined leads to increases in intrinsic motivation, more creativity and more cognitive flexibility compared to behavior that is controlled by other, external factors (Deci & Ryan, 1987). Future research is required to find out whether the option to choose a workplace for performing a writing task by oneself, such as in flexible workplaces (e.g. activity based workplaces), can influence writing performance.

Conclusion

When designing open offices the findings of the studies in this dissertation should be taken into consideration; the most important result is that writing fluency is highly sensitive to the intelligibility of background speech as even low levels of speech intelligibility can impair writing fluency. This suggests that the designs of noisy work environments should be reconsidered. They should be more adjusted for the tasks that have to be executed, for instance by making agreements on where and how to work with different tasks. Speech intelligibility seems to be a stronger impairing factor compared to speech sound level and sound source location. We have found that individual differences like noise sensitivity and inattention can influence the relation between background speech and writing performance and that task interruptions are perceived as disturbing, even in combination with background speech. Therefore, writing should be done in a quiet environment with minimal risks for task interruptions.

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Papers

Associated papers have been removed in the electronic version of this thesis.

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