Speech masking speech in everyday communication
The role of inhibitory control and working memory capacity
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ABSTRACT

Age affects hearing and cognitive abilities. Older people, with and without hearing impairment (HI), exhibit difficulties in hearing speech in noise. Older individuals show greater difficulty in segregating target speech from distracting background noise, especially if the noise is competing speech with meaningful contents, so called informational maskers. Working memory capacity (WMC) has proven to be a crucial factor in comprehending speech in noise, especially for people with hearing loss. In auditory scenes where speech is disrupted by competing speech, high WMC has proven to facilitate the ability to segregate target speech and inhibit responses to irrelevant information. People with low WMC are more prone to be disrupted by competing speech and exhibit more difficulties in hearing target speech in complex listening environments. Furthermore, older individuals with a HI experience more difficulties in switching attention between wanted and irrelevant stimuli, and they employ more resources and time to attend to the stimuli than do normally hearing (NH) younger adults.

This thesis investigated the importance of inhibitory control and WMC for speech recognition in noise, and perceived listening effort. Four studies were conducted. In the first study, the aim was to develop a test of inhibitory control for verbal responses, and to investigate the relation between inhibitory control and WMC, and how these two abilities related to speech recognition in noise, in young normally hearing (YNH) individuals.

In the second study the aim was to investigate the same relationship as in the first study to further strengthen the validity of the inhibitory test developed, as well as the importance of lexical access. It was also an aim to investigate the influence of age and hearing status on lexical access and WMC, and their respective roles for speech recognition in noise in both YNH and older HI (OHI) individuals.

Study one and two showed that, for YNH, inhibitory control was related to speech recognition in noise, indicating that inhibitory control can help to predict speech recognition in noise performance. The relationship between WMC and speech recognition in noise in YNH shifted in the studies, suggesting that this relationship is multifaceted and varying. Lexical access was of little importance for YNH, although for OHI individuals, both WMC and lexical access was of importance for speech
recognition in noise, suggesting that different cognitive abilities were of importance for the YNH and OHI individuals.

Study three investigated the relationship between inhibitory control, WMC, speech recognition in noise, and perceived listening effort, in YNH and older, for their age, NH, individuals (ONH). In study four the same relationships as in study three were investigated, albeit in OHI individuals. In both studies, two speech materials with different characteristics; open – set or closed - set, masked with four background noises; two energetic and two informational maskers, were used. The results in study three showed that less favourable SNRs were needed for informational maskers than for maskers without semantic content. ONH individuals were more susceptible to informational maskers than YNH individuals. In contrast, in study four, more favourable SNRs were needed for informational maskers. In both studies, results showed that speech recognition in noise performance differed depending on the characteristics of the speech material.

The studies showed that high WMC, compared to low WMC, was beneficial for speech recognition in noise, especially for informational maskers, and resulted in lower ratings of perceived effort. Varying results were found in study three and four regarding perceived effort and inhibitory control. In study three good inhibitory control was associated with lower effort ratings, while in study four, individuals with a HI and good inhibitory control rated effort as higher.

The results suggest that hearing status, age, and cognitive abilities, contribute to the differences in performance between YNH, ONH, and OHI individuals in speech recognition - in - noise - and cognitive tasks.

This thesis has, for the first time, demonstrated that a measure of inhibitory control of verbal content, is related to speech recognition in noise performance in YNH, ONH and OHI individuals. Results presented in this thesis also show that both WMC and inhibitory control are related to an individuals’ perception of how effortful a listening task is. It also adds to the literature that WMC is related to speech recognition in noise performance for ONH and OHI individuals, but that this relationship is not as robust in YNH individuals.
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LIST OF ABBREVIATIONS

ANCOVA = Analysis of co-variance
ANOVA = Analysis of variance
EF = Executive functions
FT = Female talker
HA = Hearing aid
HI = Hearing impaired / Hearing impairment
HINT = Hearing in noise test
HL = Hearing level
ISTS = International speech test signal
NH = Normal hearing
ONH = Older normally-hearing
OHI = Older hearing-impaired
PI = Proactive interference
PTA4 = Pure tone average (4)
RT = Response time
SNR = Signal-to-noise ratio
SRT = Speech reception threshold
SSN = Speech-shaped noise
SSNMod = SSN modulated with the envelope of FT
WM = Working memory
WMC = Working memory capacity
YNH = Young normally-hearing
**INTRODUCTION**

Information is often transferred as an acoustical signal via internet, radio, TV, mobile phones and other media. Listening to speech in a noisy environment is difficult. The speech signal is compromised by physical properties of surrounding noise and speech, which competes on a central level.

Hearing is critical for spoken communication, and human communication is more than just segregating and recognising speech. According to Plomp (2002), speech is highly redundant, and humans can handle both spectral and temporal smearing of the speech signal to considerable extent before it becomes unintelligible. Based on such facts, it is evident that cognitive factors play an important role in speech perception (Plomp, 2002). Early research within hearing science dealt with the psychophysical aspects of hearing, not considering cognitive factors as important in speech perception (Plomp, 2002).

Over the years, interdisciplinary fields combining hearing research and cognitive research have emerged (Edwards, 2016). Cognitive Hearing Science (Arlinger, Lunner, Lyxell & Pichora-Fuller, 2009) is one such interdisciplinary research field integrating auditory - and cognitive factors.
BACKGROUND

Previously, hearing research and cognitive research were considered separate fields, which over the last few decades have been combined, resulting in an increase in interdisciplinary research publications (Arlinger et al., 2009). Factors which have influenced the emergence of the field involve the need to understand how humans listen to, and perceive speech in more realistic auditory scenes, how age-related changes impact sensory and cognitive abilities, and how means of communication and technology can be improved and help performance in everyday functioning for individuals with and without impairments (Arlinger et al., 2009).

How interfering speech disturbs a listener is important to know to be able to understand different communicative difficulties some individuals experience, in particular people with a hearing impairment, but also for older people and people with decreasing cognitive ability (Heinrich & Schneider, 2011; Rajan & Cainer, 2008; Tun, O’Kane & Wingfield, 2002).

Various measures to evaluate the ability to perceive and understand spoken communication are available in research. Different levels of speech processing are more or less dependent on functions such as identification of words in noise (such as the Hagerman speech test (Hagerman, 1982), or speech understanding (as in speech tests with contextual information (for example the Swedish Hearing In Noise Test (HINT), Häggren, Larsby & Arlinger, 2006). Various tests tax cognitive capacity differently and therefore also the demands on central processing (Larsby, Häggren & Lyxell, 2012).

Cognitive functions correlate with understanding speech in noise (Lunner, 2003), and age-related declines in cognitive functions such as working memory capacity (WMC) and speed of processing have been presented (Hällgren, Larsby, Lyxell & Arlinger, 2001a; Häggren, Larsby, Lyxell & Arlinger, 2001b; Rönnberg, 1990). To be able to describe a more complete image of the negative effects on speech understanding in noise, it is important to include speech-in-noise tests with different background maskers as well as cognitive tests and measures of perceived effort (Larsby, Häggren, Lyxell & Arlinger, 2005).
HEARING, HEARING IMPAIRMENT, AGE

Human communication is crucial for establishing and maintaining social relationships. Loss of hearing can lead to social isolation, stigmatization and difficulties when communicating. Not hearing can also result in social exclusion due to discriminatory behavior from the surrounding people. Hearing loss is frustrating, not only for the person experiencing it, but also for the people trying to communicate with the person, as the means of communication decrease for both parties (Schneider et al., 2010).

Central presbyacusis refers to the aging process in the auditory parts of the central nervous system causing changes in auditory perception. These age-related changes lead to difficulties in perceiving sound and/or speech communication performance (Humes et al., 2012). In combination with the changes in auditory perception, age-related cognitive decline influences processing of auditory information and speech perception (Humes et al., 2012). Focusing on, switching between, and ignoring auditory stimuli increases cognitive load, and adding a hearing impairment increases further load on the cognitive system (Koelewijn et al., 2015). The person struggling to hear the message from a conversation might experience frustration when trying to sift between the different auditory stimuli taxing the cognitive resources (Rudner, Rönnberg & Lunner, 2011).
LISTENING TO SPEECH UNDER ADVERSE CONDITIONS

Adverse listening conditions can be defined as “any factor leading to a decrease in speech intelligibility on a given task relative to the level of intelligibility when the same task is performed in optimal listening situations” (Matty, Bradlow, Davis & Scott, 2013, pp. 1). Every day individuals engage in communication situations with other human beings in sound environments filled with background noise and/or competing talkers (Matty et al., 2013). Competing signals in the surrounding auditory scene can be caused by, for example, acoustic distortions (e.g., reverberation) or other people talking. Various background noises carry different masking characteristics that can lead to decreases in speech intelligibility (Schneider, Li & Daneman, 2007).

ENERGETIC MASKING

Energetic masking refers to when the physical characteristics, acoustic energy, of background noise interfere with the acoustic energy of target speech causing interruptions in intelligibility (Brungart, 2001; Durlach et al., 2003; Mattys, Brooks & Cooke, 2009; Schneider et al., 2007). In order for energetic masking to effectively interfere with the target signal, it is highly dependent on how the acoustic characteristics of the masker and target signal interact. If the energetic masking is concentrated in to different spectro-temporal regions than, for example, target speech, speech processing might still be quite successful and intelligibility high. Speech intelligibility can also be aided by fluctuating amplitude, meaning the noise contains gaps or glimpses in which target words could be heard through or in-between distracting noise (Freyman, Balakrishnan & Helfer, 2004; Moore, 2013; Plomp, 1994). When a noise without fluctuating amplitude, such as steady-state noise, masks target speech, little segregation between target speech and masker is offered (Cooke, 2006). However, separating target speech from distractor noise might be aided by time of onset, spatial separation or differentiating between acoustic properties of the target and distractor noise (Matty et al., 2013; Moore, 2013).

INFORMATIONAL MASKING

Informational masking refers to when the intelligibility of speech is reduced due to the informational content of a masker. Similarities between the target speech and the competing speech increase informational masking, making the target speech more difficult to segregate (Moore, 2013), thereby interrupting more central processes and increasing
cognitive load (Brungart, 2001; Cooke & Lu, 2010; Durlach et al., 2003; Moore, 2013). If the maskers used are talkers of the same sex, or the same talker used in both target condition and masker condition, as well as if the distracting speech has meaningful content, segregation of the speech streams is more difficult (Brungart, 2001; Helfer & Freyman, 2008). Furthermore, listeners report more difficulties identifying target speech in a listening situation with multiple talkers, compared to when only one talker is competing with target speech (Agus, Akeroyd, Gatehouse & Warden, 2009). Spatial separation of the speech streams can facilitate speech intelligibility, thereby reducing informational masking (Moore, 2013). Perceiving the speech streams as originating from different locations is a common occurrence in everyday listening situations (Moore, 2013).
THEORETICAL FRAMEWORK: COGNITION AND SPEECH RECOGNITION

COGNITION

Cognitive psychology aims to study human behavior in order to understand cognition (Eysenck & Keane, 2015). This is something that can be done by observing human behavior while different cognitive tasks are to be solved. Humans use cognition to understand and make sense of the environment, make decisions and act upon those decisions accordingly (Diamond, 2013; Eysenck & Keane, 2015). The internal processes involved in cognition are thinking, learning, reasoning, memory, attention, language, perception and problem solving (Eysenck & Keane, 2015).

WORKING MEMORY

Working memory (WM) refers to the ability to store and maintain information over a brief period of time, manipulating it, and using it to solve problems and / or make decisions (Dennis & Cabeza, 2013).

Baddeley (2012) describes WM as: “a complex interactive system that is able to provide an interface between cognition and action, an interface that is capable of handling information in a range of modalities and stages of processing” (Baddeley, 2012, p. 18).

Baddeley’s multi-component model of WM incorporates the visuo-spatial sketchpad, which processes visuo-spatial information; the central executive, which is responsible for attentional control, and includes a phonological loop; and the episodic buffer, which offers short-term storage and multimodal processing (Baddeley, 2012). The central executive is divided into four dimensions: focused attention, divided attention, task switching, and interface with long-term memory (LTM) (Baddeley, 2012). The episodic buffer offers the possibility to hold chunks of information (integrated episodes) from different modalities in mind. This in turn offers a buffer and a link between WM, perception and LTM (Baddeley, 2012).

One of the components of WM is the phonological loop. The phonological loop consists of two parts, a store where phonological information can be temporarily stored, and the rehearsal process, where memory traces can be kept through active repetition (Baddeley, 2012).

When investigating the phonological loop in relation to language, Baddeley found that WM is crucial for acquiring vocabulary and reading skills, both in young children with and without normal language acquisition. The investigations he conducted on the
phonological loop in relation to LTM, led to a discovery that LTM and the phonological loop are linked together.

Rönnberg, Rudner, Foo & Lunner (2008) describe that, not only is heard and spoken information processed and stored in memory, but also speech - read and signed material. This implies that the phonological loop is not limited to only auditory information, but phonological information regardless of how it is presented.

WM is crucial for a great number of human attributes, such as decision - making, making sense of written and spoken communication, and reasoning (Diamond, 2013; Eysenck & Keane, 2015). When attending a cocktail party, or in surroundings where listening is a difficult task, individual cognitive abilities, there among WMC, are important (Larsby et al., 2005; Lunner, 2003; Lunner & Sundwall-Thorén, 2007).

When a listening task becomes difficult, and some information is obscured due to interfering noise, some of the cognitive capacity can be allocated to decipher what was said and piece the information together (for a review see Mattys et al., 2013). Listening to speech under adverse listening conditions involve processing and storing information (WM), while inhibiting competing noise or speech (Engle, 2002; Ellis & Munro, 2013).

Sörqvist & Rönnberg (2012) showed in their study that domain - general cognitive processes, such as WMC, are important for successful speech processing in suboptimal listening conditions (Sörqvist & Rönnberg, 2012). Successful speech recognition is dependent on various factors, such as the characteristics of the background noise, and the level of the signal compared to the noise. When much information is lost due to adverse listening conditions, individuals rely much on cognitive skills to unravel the message (Larsby, Hälgren & Lyxell, 2008, 2012; Lunner & Sundewall-Thorén, 2007). One might compensate for the degraded speech signal by using, for example, context, speech reading, and vocabulary to reach comprehension (Larsby et al., 2012; Lunner & Sundewall-Thorén, 2007). Engle & Kane (2004) found that individuals with lower WMC are poorer at actively maintaining goals in memory, and resolve conflict between relevant and irrelevant information arising from competing information, than individuals with high WMC.

EXECUTIVE FUNCTIONS

Executive functions (EF) refers to a set of mental processes enabling individuals to pay attention, control and direct focus, and override automatic responses when necessary (Diamond, 2013; Miller and Cohen, 2001). Exerting control over responses is effortful and demands awareness and self - control, unlike relying on automatic responses (Diamond,
There are generally three core EF: inhibition (i.e. inhibitory control or cognitive control), shifting (cognitive flexibility), and working memory (WM) (Dennis & Cabeza, 2013; Diamond, 2013).

INHIBITORY CONTROL, AND COGNITIVE FLEXIBILITY

Inhibitory control refers to the ability to focus on a target stimuli, control behavior, thoughts and emotions (Diamond, 2013). To not let our bottom – up (automatic) override our top – down (controlled) processes. If someone speaks a name in a crowd, which you perceive as being your name, usually the bottom - up overrides the top - down processes and attention is drawn to where you thought you heard your name. However, if something more important drives our goals we might choose, actively, not to attend to the voice in the crowd, hence using our top - down attention to override automatic responses (Diamond, 2013; Eysenck & Keane, 2015).

One aspect of inhibitory control is cognitive inhibition (Diamond, 2013). Cognitive inhibition refers to the ability to resist proactive interference, memory intrusions from earlier acquired information, or retroactive interference, from items presented later (Nigg, 2000). Cognitive inhibition is thought to co-occur with, and generally aid WM (Diamond, 2013). By deleting irrelevant information from our limited storage capacity, and suppressing extraneous thoughts, inhibitory control supports our WM. It is also thought that WM supports inhibitory control, in order to keep a goal actively in mind to solve a task. Goal maintenance decreases the risk of making an inhibitory error (Diamond, 2013).

Engle & Kane (2004) incorporate cognitive inhibition in their two - factor model of WM. They mean that WM is the ability to maintain goals active in memory to easily be retrieved, while inhibiting distractors and interference (Diamond, 2013; Engle & Kane, 2004). Baddeley (2012) also incorporated inhibitory control and cognitive flexibility in his model of WM, where he calls these abilities functions of the central executive; multitasking, shifting between tasks or retrieval of information, and the ability to actively attend to or inhibit information (Baddeley, 2012; Diamond, 2013).

Friedman & Miyake (2004) divide inhibition in to three, main separate functions; prepotent response inhibition, resistance to distractor interference, and resistance to proactive interference (PI). Prepotent response inhibition is the ability to suppress automatic responses, and directly linked to frontal lobe activity (Friedman & Miyake, 2004). Resistance to distractor interference is the ability to resist interference from stimuli in the surrounding environment which is not relevant to solving a task (Friedman &
Resistance to distractor interference has been linked to selective attention, and studies have shown that older individuals are more susceptible to distractor interference than young individuals (Earles et al., 1997). The ability to resist memory intrusions from previously presented relevant information, which is no longer relevant, is known as resistance to PI (Friedman & Miyake, 2004). It has been shown that prepotent response inhibition and resistance to distractor interference correlate, but that they are not related to resistance to PI (Friedman & Miyake, 2004). The separability of these constructs may be due to differences in task demands. For resistance to distractor interference and prepotent response suppression, the distraction comes from external stimuli, and failure to disregard the distraction leads to task neglect. Resistance to PI however involves internal distractions as the stimuli originates from previously relevant information intruding into memory. The person experiencing interference from previously presented stimuli exhibits difficulties distinguishing irrelevant from relevant information (Friedman & Miyake, 2004).

Cognitive flexibility is another core EF, and refers to the ability to change perspective spatially, or changing how we think about something (Diamond, 2013). Cognitive flexibility builds on inhibitory control and WM. The notion that cognitive flexibility builds on inhibitory control and WM derives from the ability to change perspectives spatially, which involves inhibiting previous perspectives, and activating new perspectives in to WM (Diamond, 2013).

**LEXICAL ACCESS**

Lexical access refers to the process in which individuals access words from the mental lexicon (Field, 2003). How listeners identify and decode words in a fluent speech stream involves lexical access. Mental processes convert the raw acoustic speech signal in to a sequence of words, which forms humans’ perception of language (McQueen & Cutler, 2001). Spoken word access is seemingly automatic and effortless (McQueen & Cutler, 2001), although spoken words, unlike written words, are not divided by spaces, a listener can perceive acoustic cues signalling word boundaries (Newman, 2016). When a speech stream is identified, several mental representations are activated in memory, and lexical decision occurs based on the match with the input signal (Newman, 2016). If the speech signal is degraded, by for example a HI or background noise, lexical decision - making can be less certain and retrieval of lexical items slower (Wagner, Toffanin, & Başkent, 2016).
COGNITION AND ADVERSE LISTENING CONDITIONS

The interplay of cognitive abilities and hearing has, over the years, emerged into an interdisciplinary field known as cognitive hearing science (Arlinger et al. 2009). High WMC (Lunner, 2003) and resistance to PI (Ellis & Rönnberg, 2014; Stenbäck, Hällgren, Lyxell & Larsby, 2015) have been shown to be important predictors of speech recognition in noise and successful speech processing under adverse listening conditions. Among others, Larsby et al. (2008, 2012) showed that successful speech recognition is largely dependent on the level of noise compared to the signal. When there is not enough auditory information available, individuals rely much on cognitive abilities. When speech recognition reaches a level of 80%, cognition serves an important role, and a higher purpose, than on levels of speech recognition where half the information is lost or obscured due to interfering stimuli (Larsby et al., 2008, 2012; Lunner & Sundewall-Thorén, 2007). Several factors can lead to a listening condition being considered severe. In everyday communication individuals have to engage in conversations where syllables or whole words are masked by interfering noise or speech, rendering parts of a conversation unintelligible. In order to measure cognitive abilities and hearing status, and what difficulties may arise in every day listening situations, solid methods are of importance (Arlinger et al., 2009).

The relationship between WMC and young normally - hearing (YNH) individuals’ ability to listen to speech in noise is not as robust as the relation is older normally - hearing (ONH), or older HI (OHI) individuals (Besser et al. 2013). Differences in WMC between young and older listeners might impact results as the younger listeners, compared to older listeners often depict significantly higher WMC, due to a general age - related decline in WMC. The possibility that individuals with higher WMC can deploy more resources in order to successfully resolve conflict arising between target speech and masker, might especially manifest at lower signal-to-noise ratios (SNRs), where listening conditions are unfavourable. Performance on a speech - in - noise task might be predicted by assessing WMC and inhibitory control (Ellis & Rönberg, 2014; Stenbäck, Hällgren, Lyxell & Larsby, 2015, 2016).
LISTENING EFFORT

Listening to speech under adverse listening conditions, when the signal is distorted by background noise or an HI, increases the amount of effort needed to listen to and comprehend a message.

Listening effort has previously been investigated using various methods (see for example Koelewijn et al., 2015; Larsby et al., 2005; Zekveld et al., 2014), e.g. pupillometry, which is used to quantify cognitive processing load by measuring pupil dilation in relation to task demands and cognitive load (Koelewijn et al., 2015; Zekveld et al., 2014).

McGarrigle et al. (2014) measured listening effort by using a dual task test, where accuracy or reaction time in the secondary task reflected objective listening effort.

Larsby et al. (2005) investigated cognitive performance and self-rated perceived effort in speech processing tasks in YNH, ONH, young HI, and OHI participants. The participants rated perceived listening effort using a CR-10 scale, the Borg scale (Borg, 1982). The scale enables the participant to use numbers between 0 -10, where 0 is no effort at all, and increasing numbers depict increasing sense of effort.

Lemke & Besser (2016) propose a distinction between different types of listening effort; perceived effort, which refers to the subjective measure of how effortful a listening task is; objective effort which refers to processing load, i.e. how much resources are allocated to the task. They further propose that processing effort is the extra amount of resources needed to be allocated towards a task when the listening situation is suboptimal (Lemke & Besser, 2016).

In this thesis, perceived listening effort, subjective effort, is investigated by using the CR - 10 Borg scale (Borg, 1982). As previously mentioned, the ratio scale enables the participant to rate perceived listening effort by using numbers on a scale, where increasing numbers correspond to higher perceived effort. The scale also includes category scaling, where verbal expressions such as ‘no effort at all’, ‘moderate effort’, ‘very effortful’, correspond to the ratio scale.
OVERALL AIMS

The overall aim of the thesis was to acquire theoretical knowledge and develop methods to assess how masking speech interferes with speech recognition. The project’s focus was investigating and describing factors involved in informational masking. Specific questions of interest were:

- How is the ability to perceive speech in noise, and the perceived listening effort, affected by informational masking, or more specifically, how does the linguistic content of the masker compete with the target speech?
- How is the ability to perceive speech in noise affected by competing speech and specific listening situations? What are the demands on cognitive and perceptual abilities when discriminating sounds, words and sentences in noise?
- How does hearing ability, age, and cognitive factors influence the ability to process and perceive speech in noise; especially the ability to focus on target speech while inhibiting distracting maskers?

In studies one and two, the main focus was investigating the last question, and evaluate valid methods to investigate the first and the second question. In studies three and four, the first and second questions were focused.
ETHICAL CONSIDERATIONS

The regional ethics committee in Linköping, Sweden, has, in accordance with the declaration of Helsinki, approved this project (Dnr: 2012/105-31).
In all four studies, the participants were informed of the aims of the project. They were sent or presented with an information letter prior to testing. All participants were informed that testing was voluntary, and that it could be interrupted by the participant, at any time, without further explanation. The participants’ names were replaced by a code for anonymity and confidentiality purposes.
GENERAL METHODS

AUDITORY TESTS

PURE TONE AUDIOMETRY

Pure tone audiometry was performed for the frequencies 125, 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz.

HAGERMAN SPEECH-IN-NOISE TEST

The Hagerman sentences (Hagerman, 1982) are five word matrix-type sentences in Swedish with low semantic redundancy and the same grammatical structure; name, verb, number, adjective, and noun (example translated from Swedish: Jonas has nine big rings). Low semantic redundancy prevents guessing of words based on the semantic context provided by the rest of a sentence. The sentences were presented in background noise targeting speech reception threshold levels (SRT) for either 50% or 80% word recognition. After a practice round of 20 sentences, which was administered in order for the participants to get acquainted with the procedure and help reduce training effects, ten sentences were presented in each criterion (50%, 80%), and each background masker, to obtain the correct SRT levels.

HINT- SWEDISH HEARING IN NOISE TEST

The Swedish HINT sentences (Hällgren et al., 2006) consist of 250 sentences divided into 25 phonemically balanced lists. The sentences consist of three to seven words (example: “She sat down by the fire”), and are designed to be of higher semantic redundancy and more ecologically valid than the Hagerman sentences. In this study the noise level was varied in an adaptive staircase procedure in steps of 2 dB to obtain an intelligibility level targeting SRT for 50% correct keywords or SRT for 50% correct whole sentences (Larsby et al., 2012). Each participant was presented with a list of 20 sentences for each SRT criterion as practice. To determine SRT for each criterion and each background masker, 20 sentences were presented, where mean SNRs were calculated based on the last 10 sentences in each list.

BACKGROUND NOISE

In studies one and two, a slightly (10%) amplitude modulated speech-shaped noise (SSN) was used to mask target sentences. The noise is the original noise used to mask the
Hagerman sentences (Hagerman, 1982), and has the same long-term average spectrum as the speech material.

Four different background noises were used to mask either the Hagerman or the HINT sentences in studies three and four. The Hagerman sentences were presented in the same SSN as in study one and two, while the HINT sentences were presented in the original HINT noise (Hällgren et al., 2006) which contains no amplitude modulation; the International speech test signal (ISTS) (Holube, Fredlake, Vlaming & Kollmeier, 2010); a single female talker reading a passage from a Swedish daily newspaper (henceforth referred to as FT), and a modulated noise constructed by modulating the SSN with the envelope of the FT (henceforth referred to as SSNMod). The envelope was calculated by extracting the instantaneous amplitude of the FT, which was low-pass filtered with a cut-off frequency of 32 Hz (for details see Agus et al., 2009). Using only the envelope of the FT resulted in the same temporal variations and frequencies as the FT, but lacking semantic information.

In the ISTS (Holube et al., 2010) there are six different languages; American-English, Arabic, Mandarin, French, German, and Spanish. The speakers, six women, were recorded while reading the same story. The recorded stories were then split into speech segments, rendering the material non-intelligible. The material is meant to sound like natural speech, and be recognisable as composed of real speech, but contain nothing intelligible.

The FT in this study is a single female speaker reading an article from a daily newspaper about Swedish pensions and politics. The recording was sampled with a sampling frequency of 44.1 kHz. The FT was recorded from a sound attenuated booth, minimising possible interference from background noise. Speech pauses were limited to 600 ms and any initial clicking sounds or champs before a sentence were removed.

COGNITIVE TESTS

THE READING SPAN TEST

The Reading Span test taxes short-term storage and explicit processing simultaneously. The test is comprised of three-word sentences in sets of two to five sentences. The sentences are presented on a screen word-by-word. The task is to decide whether the sentence presented is plausible or nonsense. After each set the participant is asked to recall either the first or the last word of each sentence in a set. A correctly recalled
word scores one point and the total score is used as a measure of WMC, regardless of recall order (cf., Rönnberg, Arlinger, Lyxell, & Kinnefors, 1989).

THE SWEDISH HAYLING TASK

The Hayling task was developed by Burgess & Shallice (1996) to evaluate initiation and, the EF, inhibition. The task is to complete highly predictable sentences with a logical and grammatically correct word (initiation), or with an illogical, but as far as possible, grammatically correct word (inhibition) (Bloom & Fischler, 1980; Burgess & Shallice, 1996) e.g. He mailed the letter without a ____? Where a correct response in the initiation condition could be stamp, and a correct response in the inhibition condition could be banana. If both a semantically and grammatically correct word is responded in the initiation condition, a normal spontaneous use of language in an ordinary contextual configuration is noted. In the inhibition condition an error is noted if the word is the straight - forward completion (3 points), or related to the correct answer, or is grammatically incorrect (1 point). Test results are computed by comparing differences in reaction times (RT) between the initiation condition and the inhibition condition, as well as error rates given by the number of incorrect answers in initiation test versus how many incorrect in inhibition test (Burgess & Shallice, 1996).

In the Swedish version of the task (Stenbäck et al., 2015), the initiation condition is repeated with the same instructions as for the inhibition condition. Presenting the participants with the initiation condition, asking them to complete the sentences with a semantically non - related but grammatically correct word, ensures that the participants must engage in active suppression as the logical word has already been activated in the initiation condition (Borella, Ludwig, Fagot & De Ribaupierre, 2011; Stenbäck et al., 2015).

DEVELOPMENT OF THE HAYLING TASK

When developing the sentences for the Hayling task, the Swedish version, the method was adopted from Bloom & Fischler (1980), who developed completion norms for sentence contexts. In the Bloom & Fischler (1980) study, two sets of sentence contexts were developed, with different distributions of the primary response. When developing the Hayling sentences in Swedish, the appendix for the completion norms of sentence contexts comprised the basis. Several sentences could be translated in to sensible contextual sentences in Swedish, while other sentences had to be reformulated or grammatically rebuilt to be contextually useful sentences. Other sentences developed by Bloom &
Fischler (1980) were not sensible in Swedish and therefore excluded. When developing the sentences, a few rules were taken into consideration. These rules were also set by Bloom & Fischler (1980) and were adopted as rules to be followed when composing the Swedish contextual sentences. The boundaries to keep within were: only one response word per sentence; the word should make sense to the sentence; only Swedish words; no proper names, hyphenated or contracted words; avoid repetitions. One hundred high-cloze (highly predictable) sentences were developed in Swedish and 86 of those sentences were then included in the pilot study. The sentences contained three to nine words and were developed to be of very high contextual predictability.

Testing the material took approximately thirty minutes with the audiogram and the finishing of the eighty-six sentences. The audiogram took place in a sound attenuated booth and the sentence completion in a room without distractions. The sentences were read out loud, one by one, by the test leader and after completion of one sentence, the response was registered and the next sentence read.

When all the words had been registered, 60 sentences were included in the Swedish version of the Hayling task. The predictability of the expected words was computed in Microsoft Excel where the sentences and their response frequency were registered. Out of the 60 sentences included, 40 had a predictability of 100% whereas 20 sentences had a predictability of 50-90% where the words answered were either synonyms or different grammatical forms of the same word (e.g. speak / talk or eat / eaten) (Mean predictability = 94%) (Appendix 1).

The sentences were recorded in a sound attenuated booth. A female voice read all the sentences three times, twice without the finishing word and once with the finishing word. The microphone used to record the sentences was an AKG C 480 B and the microphone amplifier used was a dbx 386.

TESTING THE HAYLING SENTENCES FOR AUDIBILITY

After the recordings, a method to administer the sentences were coded in Matlab (R2012a) and presented to ten additional participants (mean age = 27.6, SD= 6.5). The participants were presented with 20 incomplete sentences masked by a speech - weighted noise. The task was to repeat the sentences and add the last missing word. The SNR varied, in an adaptive 2 dB up / 2 dB down mode, depending on if the participants repeated the sentences correctly or not. After the 20 sentences were presented, 60 new sentences were
administered, this time with a fixed SNR based on the performance in the adaptive staircase mode. The participants were asked to repeat the sentences, guess if they were uncertain, and add the missing word.

CORRECTING THE SENTENCES

When deciding which sentences were eligible to be included in the test, they had to be evaluated for correct word recognition and sentence repetition. The first calculation was conducted on the basis of evaluating how many of the words in a sentence had been correctly repeated, and then calculate the mean of correct repeated words per sentence across participants. The second calculation was based on how many of the participants who had recognised entire sentences correctly. The sentences with more than 60% correct word recognition and sentence repetition were directly qualified to be included in the Hayling task. Forty sentences with high contextual predictability and high percentage on word recognition and/or sentence repetition were included in the Hayling task. An additional eight sentences with high word recognition and/or sentence repetition qualified as training sentences for the Hayling task.

LEXICAL, PHONOLOGICAL, AND VERBAL TASKS

The test is a verbal information processing task divided into three separate test blocks. The participants respond by pressing buttons corresponding to yes/no. Response times are measured from the moment the letter or word appears on a screen until the participant has pressed the response button.

Physical matching. - The task is to decide whether two presented letters are identical or not (example, A-A or A-B).

Lexical access. - The task is to decide if a presented three-letter word is a real word or a non-word. The real words presented are all familiar Swedish words (Allén, 1970).

Rhyme. - The participant is to decide if two presented words rhyme or not. They are instructed to disregard the spelling of the words.
Verbal ability. - This test measures general word knowledge and vocabulary, and consists of 29 five-word sequences. The task is to decide whether two of the words in a sequence of five are antonyms. Each participant has five minutes to complete the test (e.g. in English: beautiful, old, sad, fast, young).

DICHOTIC LISTENING TASK

In a dichotic listening task, central auditory processing is assessed by presenting different stimuli to both ears simultaneously. The dichotic listening task used in study one was word pairs of one-syllable words (consonant-vowel) with combinations of stop consonants and “a”, e.g. ba, ga, ka, ta, da and pa, presented simultaneously to both ears. The participant reports either only what is heard in one of the ears and ignores the stimuli to the other ear (directed condition), or listens to and reports what is heard in both ears (free condition) (Hugdahl et al., 2009).

SIMON TASK - INHIBITION

The Simon task measures response inhibition. The instructions are to press a button when either a green or a red circle appears on either the left or the right side of a screen. The participant is to always press the right button when the green circle appears, even if it appears on the left side of the screen and the left button for red even if it appears on the right side of the screen. When the circle appears on the same side as the button to press it is a congruent response and when it appears on the opposite side as the button to press it is an incongruent response. The participant is to inhibit the response to press the wrong button when the coloured circle appears on the wrong side (Weldon, Mushlin, Kim, Sohn, 2013). Response times were measured from the moment the circle appeared (baseline) until the participant pressed the response button.
PARTICIPANTS

STUDY 1

Thirty young adults (mean age = 23.6 years, SD= 4.4), were recruited from the medical programs at Linköping University, the faculty of Medical and Health Sciences, Sweden, and from Lunnevads folk high school, Linköping Sweden. The participants had normal hearing (NH) (< 20 dB HL on both ears) as measured with pure tone audiometry, and were all native speakers of Swedish.

STUDY 2

Two groups participated in study two.

Group 1 consisted of 46 young adults (mean age = 23 years, SD= 3.7), with NH (< 20 dB HL on both ears). They were recruited from Linköping University, The faculty of Medicine and Health Sciences, Sweden, and the music programs at Lunnevad folk high school.

Group 2 consisted of 40 older adults (mean age = 66.2, SD = 8.7), with a mild to moderate bilateral hearing impairment (pure tone average (4) (PTA4) = 33.9 dB HL, SD = 8). They were recruited from the hearing clinic at Linköping University hospital. Hearing thresholds were determined using pure tone audiometry. All participants had Swedish as their native language. The participants did not wear hearing aids during the auditory tests.

STUDY 3

Two groups participated in study three.

Group 1 consisted of 24 young adults (mean age = 25.7 years, SD =5.5) with NH (< 20 dB HL on both ears). They were recruited from the faculty of Medicine and Health Sciences, Linköping University, Sweden, and the music programs at Lunnevad folk high school.

The second group were older adults (mean age = 59.3 years, SD = 6.5), with NH in relation to their age (ISO 7029:2000, 2000) (PTA4 = 8.75, SD = 4.2). They were recruited from the Faculty of Educational Sciences, and by word of mouth from other participants and acquaintances. All participants reported normal neurological health, and Swedish as their native language.

STUDY 4

Twenty-four individuals with a mean age of 69.7 years (SD = 5.4), with a mild to moderate hearing impairment (PTA4 = 35.52, SD = 9.4) participated. They were recruited from the hearing clinic at Linköping University Hospital, Sweden, by word of mouth, and
information letters to various local organizations. All participants reported Swedish as their native language and normal neurological health. Hearing thresholds were determined using pure tone audiometry. The participants did not wear hearing aids during the auditory tests.
SUMMARY OF THE PAPERS

STUDY 1

Aim

The aim of the study was to develop a task involving inhibitory control of verbal responses in Swedish in order to investigate the relationship between inhibition (cognitive inhibition), and WMC, and their respective roles in speech recognition in noise performance in YNH individuals.

Method

Pure tone audiometry was administered to determine hearing thresholds. The Hagerman sentences were administered in a sound attenuated booth. The noise used to mask the sentences were the Hagerman original SSN (Hagerman, 1982), targeting SRTs for 50 % and 80 % word recognition respectively. The dichotic listening task (measure of inhibition and simultaneous auditory processing of multiple stimuli), and the Swedish Hayling task (measure of cognitive inhibition) were also administered in a sound attenuated booth. After each list in the Hayling task, the participants rated perceived effort using the Borg scale (Borg, 1982). The Reading Span test (measure of WMC), the Simon task (test of inhibition), and verbal information processing task were administered visually on a computer screen.

Results and Discussion

The results showed that the Hayling task was a suitable measurement of (cognitive) inhibition, and that high verbal ability was beneficial for performance in the Hayling task. The individuals with high performance in the Hayling task, also performed well in the speech - in - noise task, suggesting that these individuals were good at resisting interference from irrelevant stimuli. High WMC was beneficial, both for performance in the Hayling task, and for performance in the speech - in - noise task. Having good cognitive inhibition, as well as high WMC facilitated speech recognition in noise performance in YNH individuals.
STUDY 2

Aim

The aim of the study was to investigate the relative contribution of age and hearing status on WMC and lexical access, and their respective roles when listening to speech under adverse conditions in YNH and OHI individuals. The study also aimed to strengthen the presumption from study one that the Hayling task is a suitable measure of cognitive inhibition, and can be used to predict speech recognition in noise performance.

Method

Pure tone audiometry was performed to determine hearing thresholds. The auditory test; the Hagerman speech - in - noise test, as well as the Hayling task (measure of cognitive inhibition), were presented in a sound attenuated booth. The cognitive tests; the Reading Span test (measure of WMC) and test of verbal information processing, were presented visually on a computer screen in a quiet office.

Results and Discussion

The results showed that good verbal information processing skills were beneficial for OHI individuals, but had little impact on performance for YNH individuals when presented with the Hagerman speech - in - noise test. Similar results were observed when investigating WMC in relation to speech in noise performance; no relation was found for YNH individuals, but high WMC was beneficial for speech in noise performance for the OHI group. While more favourable SNR was needed to reach 50 % than 80 % word recognition in both groups, the OHI group had larger variation in their SNRs compared to the YNH group. Cognitive inhibition, as measured with the Hayling task, showed YNH individuals with good cognitive inhibition performed better in the speech - in - noise task than individuals with poorer cognitive inhibition. The results in the study suggest that hearing ability, WMC and cognitive inhibition are important factors when listening to speech under adverse conditions.

STUDY 3

Aim

The study aimed to investigate the relationship between WMC, inhibitory control, age, and speech recognition in noise in YNH and, for their age, ONH individuals, using
two different speech materials; one with high, and one with low semantic context, presented in four different background noises; two energetic maskers and two informational maskers.

Method

Pure tone audiometry was performed to determine hearing thresholds. The auditory tests; the Hagerman test and the HINT, as well as the cognitive test the Hayling task, were administered in a sound attenuated booth. The Hagerman and the HINT were presented in four background noises; one SNN with small (10%) or no modulations; a SSN modulated with the envelope of a single talker, SSNMod, sharing some characteristics with speech, with gaps and slow variations in amplitude, but without any semantic information; the ISTS, which is composed of segments of speech, where syllables from six different languages are assembled into a non-intelligible continuous speech stream; and a FT reading a passage from a Swedish daily newspaper. After each background noise the participants rated listening effort. The Reading Span test was administered as a measure of WMC, and the Hayling task as a measure of inhibitory control.

Results and Discussion

The results showed a difference in SNRs depending on the type of noise used to mask the target sentences in the Hagerman test as well as in the HINT. An interaction between noise type and group in the Hagerman test, showed that the ONH individuals were more susceptible to an informational masker than the young participants, as the YNH could handle less favourable SNRs. For the HINT, no differences in performance could be observed as a result of group. Further results showed that high WMC was associated with less favourable SNRs for the SSN masker in the Hagerman test, and when using informational maskers in the Hagerman test and the HINT. Results also showed a relationship between inhibitory control and performance in the Hagerman speech - in - noise test when informational maskers were used, however, the results suggest that this relationship was influenced by age. A possible age - related decline in both hearing thresholds and cognitive abilities might contribute to the difficulties older listeners experience in adverse listening situations.

Listening effort was associated with WMC and inhibitory control, where lower ratings of effort related to higher WMC and better inhibitory control when informational maskers were used in the speech - in - noise tasks. We argue that higher WMC helps resolve
the conflict between the target speech and the competing speech, by leaving more cognitive resources free to process and store the information, resulting in less perceived listening effort. Individuals with lower WMC resolve the conflict, although not as efficiently, resulting in greater perceived listening effort.

STUDY 4

Aim

The aim of the study was to assess if speech in noise performance, and listening effort, in OHI individuals differed depending on individual cognitive abilities such as WMC and inhibitory control. This was investigated by using two speech materials; one with and one without semantic context, and four background noises; two energetic maskers, and two informational maskers.

Method

Pure tone audiometry was performed to determine hearing thresholds. The auditory tests; the Hagerman test and the HINT, as well as the cognitive test, the Hayling task, were administered in a sound attenuated booth. The Hagerman and the HINT were presented in the same four background noises used in study three. The participants, who were HI, wore no hearing aids during the auditory testing, as it was of importance to assess speech recognition performance in unaided conditions. After each background noise the participants were asked to rate their perceived listening effort. The Reading Span test was administered as a measure of WMC, and the Hayling task as a measure of inhibitory control.

Results and Discussion

Results showed that performance in the Hagerman test differed depending on word recognition criterion and the characteristics of the masker. Results also showed that WMC was related to speech in noise performance, where higher WMC was beneficial for speech recognition, especially when informational maskers were used, even when controlling for age and hearing thresholds. Inhibitory control was of most importance for speech recognition when an informational masker was used in a speech material without semantic context. The results also showed that listening effort was rated as greater in the HINT than in the Hagerman test by individuals with high WMC.
DISCUSSION

In this thesis speech recognition in noise, and listening effort, have been investigated in relation to cognitive abilities such as WMC, inhibitory control, lexical access, and verbal ability. In order to assess inhibitory control of verbal responses in relation to speech recognition in noise, a Swedish version of the Hayling task was developed. To the best knowledge of the authors, the Hayling task had not, previous to the presented studies, been used in relation to speech recognition in noise when assessing inhibitory control. It was of importance to incorporate a valid measure of initiation and inhibitory control of verbal responses, in Swedish, as several of the existing tests of inhibitory control lack semantic or linguistic elements of inhibition.

The results showed that good inhibitory control was associated with better performance in a speech-recognition task in young normally-hearing individuals. Further findings showed that good inhibitory control was also related to speech recognition in noise in older individuals with normal hearing and hearing impairment. For ONH and OHI individuals, good inhibitory control was of particular importance in conditions when informational maskers competed with the target speech. The relationship between speech recognition in noise, inhibitory control, and WMC was strongly influenced by age in a sample of YNH and ONH individuals. In both older normally-hearing and hearing impaired individuals, WMC was crucial for speech recognition performance, regardless of the characteristics of the speech material, and which SRT was targeted. This relationship was not as robust in YNH, where varying results were found for the link between speech recognition in noise and WMC.

The results also include greater difficulties for ONH, compared to YNH, to resolve the conflict between target speech and informational maskers, and that OHI individuals needed significantly more favourable SNRs when informational maskers masked target speech, compared to energetic maskers.

Good inhibitory control and high WMC were generally associated with lower ratings of listening effort, except in OHI individuals, where good inhibitory control was associated with higher ratings of effort when an informational masker was used.
The results in the present thesis suggest that a HI, as well as age, are influencing factors on the relationship between speech recognition in noise, perceived listening effort, and cognitive factors.

SPEECH RECOGNITION IN NOISE - COGNITIVE FACTORS AND AGE

The presented results from this thesis shows that YNH individuals vary in speech recognition in noise depending on differences in WMC and inhibitory control. In study one, when assessing speech recognition in noise, using the Hagerman test, masked with a SSN, YNH with higher WMC and good inhibitory control performed better than their peers with lower WMC and worse inhibitory control (Stenbäck et al., 2015). However, in study two, the relation between WMC and speech recognition in noise in YNH was not significant (Stenbäck et al., 2016). Besser et al. (2013) showed that the relationship between WMC and speech recognition in noise in YNH was not as robust as this relationship in older individuals, with and without hearing impairment. The YNH individuals in study one and two were homogenous groups, showing little (although significant) variation in WMC and speech recognition in noise, which might have impacted on the different results in the studies. In study one and two, the relationship between inhibitory control and speech recognition in noise suggested that good inhibitory control facilitated performance. It is argued that inhibitory control can be used to predict speech recognition in noise in YNH individuals, especially when little information is offered from target speech due to masking noise.

In study three, WMC was associated with better speech recognition in noise in YNH and ONH individuals when SSN, ISTS and FT were used as maskers in the Hagerman test. However, when controlling for age, only the relationship with the SSN masker remained. Speech recognition performance in the HINT was not related to WMC when controlling for age. As discussed above, WMC and speech recognition in noise in YNH showed varying results in studies one and two in this thesis, which is further strengthened by the relationship being influenced by age in study three.

In studies three and four, better speech recognition in noise was associated with good inhibitory control, when informational maskers were used in the Hagerman test. Although no significant correlations could be found between age and inhibitory control, the relationship between inhibitory control and speech recognition in noise was non-significant when age was controlled for. In study four, PTA4 was controlled for as a means of eliminating hearing thresholds as a confounding factor on this relationship.
(2013) puts forward that inhibitory control and WMC co-occur. In study one, results showed that inhibitory control and WMC were inter-correlated, supporting the notion that these cognitive abilities are interrelated. Such an interrelation between inhibitory control and WMC could explain why age might be an influencing factor on the relationship between inhibitory control and speech recognition in noise.

However, in studies one and two, good inhibitory control facilitated speech recognition in noise in the young listeners when SSN was used as masker. When assessing this relationship in young and older normally-hearing, and older hearing-impaired individuals, using both energetic and informational maskers, good inhibitory control was most beneficial for informational maskers.

In all four studies, inhibitory control facilitated speech recognition in noise in the Hagerman test, but not in the HINT material. The Hagerman test and the HINT material differ in semantic context, HINT has higher semantic context than the Hagerman test, whereas the Hagerman test has higher syntactical redundancy than the HINT material. The materials differ in sentence length, where the Hagerman test has an identical grammatical structure and consists of five-word sentences (Hagerman, 1982), whereas the HINT vary in sentence length from three to seven words, and is of higher ecological validity (Hällgren et al., 2006). The identical structure of the sentences in the Hagerman test, and the high syntactical redundancy makes them temporally predictable, offering cues when to listen for the sentences in the noise. Knowing when to listen for the target speech could have deployed inhibitory control when competing speech masked target sentences. The varying sentence length, and higher contextual content of the HINT material offer more information in to WM, and more lexical candidates to choose from in the mental lexicon, rendering inhibitory control less important for speech recognition in the HINT material.

In study one, verbal ability proved to be associated with shorter RTs and less erroneous answers in the Hayling task. High verbal ability, and/or knowledge about the context of a conversation, has been suggested to be beneficial in tasks where resistance to semantic interference is of importance (Schneider et al., 2007; Stenbäck et al., 2015; Wotton et al., 2011). In study two, high verbal ability was beneficial for lexical decision-making in a speech-recognition-in-noise task, but only in the hearing-impaired individuals. The YNH individuals, being homogenous regarding WMC, age, and hearing thresholds, might have used inhibitory control and hearing ability for speech recognition,
while the OHI individuals used a combination of lexical access and WMC to compensate for worse hearing thresholds.

In summary, WMC is important for speech recognition in noise, although in YNH individuals, cognitive factors such as inhibitory control can be a better predictor of speech in noise performance. Age is an influencing factor on speech recognition in noise performance, which may be due to age-related changes in both cognitive abilities and hearing thresholds.

SPEECH MATERIAL, SPEECH RECEPTION THRESHOLD, AGE AND HEARING IMPAIRMENT

In studies one and two, only the Hagerman test was administered. As previously discussed, this speech material is highly redundant on a syntactical level, but has low semantic context. In study two, both groups (YNH, OHI) needed significantly more favourable SNRs to reach the 50 % SRT, than the 80 % SRT, which was expected. The YNH individuals showed less variation in the SNRs needed to reach the targeted SRTs than the OHI individuals. The YNH individuals relied on hearing ability and, possibly, inhibitory control, regardless of SRT criterion, whereas the results for the OHI individuals showed that hearing ability (PTA4) was a major influencing factor on speech recognition in noise performance in both SRTs.

In studies three and four, the participants were presented with the Hagerman sentences, as well the HINT speech material. The HINT, as opposed to the Hagerman, was developed to be more ecologically valid, and of higher semantic context. As expected, in both speech materials, the 50 % word recognition / keyword criterion compared to the 80 % word recognition / 50 % whole sentence criterion needed significantly less favourable SNRs. Speech recognition performance in the two speech materials differed in study three and four. In study three, the young, and older normally-hearing groups did not differ in SNRs in the HINT material, whereas in the Hagerman material they did. We argue that the older participants relied more on contextual cues from the HINT material, supporting previously presented results by Aydelott, Leech & Crinion (2010).

In study three, in the Hagerman test, there was a main effect of PTA4 when using the variable as a co-variate, showing that PTA4 was significantly related to performance in the task. The ONH individuals had a small, but compared to the YNH, significant high-frequency hearing loss. Although this group was considered normally—hearing,
according to ISO 7029:2000, this could have influenced the speech recognition in noise performance. A few studies (Fogerty, Ahlstrom, Bologna & Dubno, 2015; de Andrade et al., 2013) have shown that high-frequency hearing loss impacts speech recognition in noise performance negatively. It is possible that the, small but significant, age-related hearing loss in the ONH individuals impacted the results as these individuals might have relied more on high-frequency consonant cues than the YNH individuals, resulting in worse performance.

Consequently, it was of importance to control for the relative contribution of PTA4 thresholds on speech recognition performance. In the HINT material, there was no main effect of the co-variante PTA4. In study four, performance in the two speech materials also differed. The OHI group performed better, i.e. achieved less favourable SNRs, in the Hagerman test than in the HINT material. These results suggest that different abilities influence speech recognition performance in the two speech materials. As discussed above, these two speech materials differ in semantic context and syntactical redundancy, but also in terms of open-set vs. closed-set material.

Previous research (Larsby et al., 2012; Lunner et al., 2012) state that choice of speech material can influence speech recognition performance based on the properties of the material. Variations in semantic context, syntactical redundancy, and/or sentence construct and length in speech materials, influence speech recognition. It is also likely that the HINT material engages higher cognitive processes, such as speed of processing and lexical ability, while in the Hagerman material, where speech recognition occurs by retrieving single words rather than whole sentences, hearing ability is the central influencing factor.

In short, the results from study three and four support the notion that speech recognition performance differ depending on the choice of speech material, but also due to age-related declines in hearing thresholds and cognitive abilities.

ENERGETIC AND INFORMATIONAL MASKERS, AGE AND HEARING IMPAIRMENT

In studies one and two, only an energetic masker was used to mask target speech. YNH individuals needed significantly more favourable SNRs to reach the 80 % SRT criterion in the Hagerman test, than the 50 % criterion, as was the case for the OHI individuals in study two, where results showed they varied more than the younger group regarding SNRs in the speech reception thresholds. The SSN used in studies one and two
was an energetic masker with little modulation (10%), hence lacking glimpses to listen in. Due to the nature of the energetic masker, the HI in the older participants complicated the listening task. Previous research (e.g., Festen and Plomp, 1990; Moore, 2013) show that HI individuals perform worse than their normally-hearing peers in SSN.

In studies three and four both energetic and informational maskers were used to mask target speech in two different speech materials. Main effects of noise type were found in both speech materials. In study three the results showed that overall SNRs were less favourable for informational maskers than for energetic maskers, although for the older (for their age normal hearing) individuals SNRs were significantly more favourable when informational maskers were used in the Hagerman test than for the young listeners. It is argued that the older normally-hearing individuals were more susceptible to informational maskers due to the linguistic content in the masker competing with the target speech.

Study four, with hearing impaired participants, showed that significantly more favourable SNRs were needed for the informational maskers compared to the energetic maskers to reach the targeted SRTs in both speech materials. Figure 1 demonstrates that for the young and older NH individuals, SNRs were less favourable for the informational maskers than for the energetic maskers. In the hearing impaired individuals, the pattern is the opposite; SNRs were more favourable for the informational maskers than for the energetic maskers. This results shows that, although age influenced SNRs in the informational maskers between the YNH and ONH individuals, the HI group were more susceptible to informational maskers than both the young, and older normally-hearing individuals (Figure 1). It is suggested that maskers containing semantic or linguistic content, in combination with the HI, complicate the listening task, as stream segregation is made more difficult due to the masking noise sharing similar characteristics with the target speech. Target speech is not solely overlapped by the energetic properties of the masker, but the informational content of the masker engages higher central processes, as previously shown, such as WMC and inhibitory control in order to help segregate the speech streams.

To summarise, informational maskers complicate a listening task by competing with target speech, engaging cognitive abilities such as WMC, lexical abilities, and inhibitory control. ONH individuals are more susceptible to informational maskers than YNH individuals, but OHI individuals are even more affected by informational maskers than their NH peers.
PERCEIVED LISTENING EFFORT, SPEECH IN NOISE, AND COGNITIVE FACTORS

In study one, perceived effort, as measured with the Borg CR - 10 scale (Borg, 1982), was only assessed in the cognitive test of inhibitory control. The scale was administered after each condition (initiation; Condition 1, and inhibition; Condition 2 and 3), in order to investigate whether participants rated effort as greater when the task was to inhibit the logical response in the task, as compared to when a logical, and seemingly automatic response was requested. Results showed that effort was perceived as significantly greater when the inhibition conditions (Condition 2 and 3) were administered, compared to the initiation condition (Condition 1). This result suggests that, when engaging more top-down processes, actively overriding automatic responses, the task was perceived as more effortful.

In relation to this outcome, the results in studies three and four, showed that informational maskers were perceived as more effortful than energetic maskers in the HI individuals (Figure 2). In the young and older NH individuals, informational maskers were
rated as less effortful than energetic maskers. However, in all three groups, higher WMC was associated with lower effort ratings (Figure 2). It has previously been discussed that energetic maskers overlap target speech with the acoustical properties, thereby reducing the intelligibility, while informational maskers engage more central processes, demanding more cognitive resources, such as WMC and inhibitory control. This is reflected in studies three and four, supporting the notion that informational maskers are more cognitively demanding than energetic maskers (Brungart et al., 2013; Koelewijn et al., 2014).

In studies three and four it was shown that individuals with high WMC rated effort as less than individuals with lower WMC. In relation to the discussion regarding cognitively demanding tasks being perceived as more effortful, having more WMC to allocate, would lead to less perceived effort. The same was shown in study three for inhibitory control, where good inhibitory control was associated with lower effort ratings. Inhibitory control and WMC are inter-correlated, leading to a proposition that these two functions co-operate and support one another. With higher capacity and better inhibitory control, less effort need to be cultivated toward the task. However, in study four, better
inhibitory control was associated with higher ratings of effort. The three groups; YNH, ONH, OHI, significantly differed in WMC (Figure 3), although when controlling for age, the main effect was non-significant. The ONH group had significantly lower WMC than the YNH group, and the OHI group had significantly lower WMC than both the YNH and ONH groups. The OHI varied in WMC within the group as well. With this in mind, already having a HI complicating the listening task, engaging more cognitive resources could lead to more perceived effort. The individuals with lower WMC, and an already taxing impairment heightening the sense of effort, have no more resources to allocate, leading to no increase in effort ratings.

Listening to speech in noise increases the demand on, some, cognitive abilities, showing that higher WMC and better inhibitory control result in lower effort ratings. ONH individuals perceive informational maskers as more effortful than energetic maskers, compared to YNH individuals, although energetic maskers are, overall, perceived as more effortful than informational maskers. Older individuals with a HI perceive informational maskers as more effortful than energetic maskers, and rate effort has greater in comparison to the YNH and ONH individuals.

Figure 3. Main effect of group on working memory capacity
CONCLUSIONS

This thesis shows that cognitive abilities, such as WMC and inhibitory control, are important factors for successful speech recognition in noise for young, and older normally hearing, and older hearing impaired individuals. Older individuals perform worse in speech - in - noise tasks when informational maskers are used, than younger individuals, with further decrease in performance for older individuals with a hearing impairment. Informational maskers complicate the listening task further for older individuals, compared to energetic maskers, where prominent factors influencing performance are age - related declines in hearing thresholds, WMC, and inhibitory control. Increasing age and decreasing hearing thresholds open into more difficulties in perceiving speech in noise, engaging cognitive resources, leading to more effortful listening situations.
FUTURE DIRECTIONS

The YNH individuals in the studies were all homogenous and showed little variation in test results, which could have had an impact on cognitive scores, as well as speech recognition in noise performance. In future studies, it would be of interest to include a larger sample of young individuals with a wider range of demographical data, as well as a young group with HI to compare to the YNH individuals.

Due to the differences in PTA4 thresholds in the young and older participants, speech recognition in noise performance could have been influenced. For future reference, it would be of interest to include an older group with clinically normal hearing, to compare to the older group with, for their age, normal hearing.

The OHI individuals were presented with the auditory stimuli without wearing hearing aids. This impacted the results as it was the unaided hearing status that was of interest for this thesis. In order to investigate the effects a hearing aid have on speech recognition performance, and / or possible effects it might have on cognitive abilities, this could be investigated in a future study, and compared to the results in the present thesis.
ACKNOWLEDGEMENTS

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REFERENCES


APPENDIX 1

Appendix. The stimulus sentences in list 1 of the Hayling task, the words produced by the participants, and the predictability of the sentences based on the produced words. N=10.

<table>
<thead>
<tr>
<th>Sentences List 1</th>
<th>Word produced</th>
<th>Predictability %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaptenen ville sjunka med sitt</td>
<td>skepp</td>
<td>100</td>
</tr>
<tr>
<td>Han postade brevet utan ett</td>
<td>frimärke</td>
<td>100</td>
</tr>
<tr>
<td>Hon smög utan att ge ifrån sig ett</td>
<td>ljud</td>
<td>100</td>
</tr>
<tr>
<td>Efter sommarlovet börjar barnen i</td>
<td>skolan</td>
<td>100</td>
</tr>
<tr>
<td>Jorden är formad som ett</td>
<td>klot</td>
<td>100</td>
</tr>
<tr>
<td>Syrénbusken stod i full</td>
<td>blom</td>
<td>100</td>
</tr>
<tr>
<td>En mening bör inledas med stor</td>
<td>bokstav</td>
<td>100</td>
</tr>
<tr>
<td>Märta tog fram gräsklipparen för att klippa</td>
<td>gräset</td>
<td>100</td>
</tr>
<tr>
<td>Polisen stannade honom då ha kört för</td>
<td>fort</td>
<td>100</td>
</tr>
<tr>
<td>Elsa trängde sig före i</td>
<td>kön</td>
<td>100</td>
</tr>
<tr>
<td>Hon bränd sig på tungan då maten var för</td>
<td>varm</td>
<td>100</td>
</tr>
<tr>
<td>Hon trivdes som fisken i</td>
<td>vattnet</td>
<td>100</td>
</tr>
</tbody>
</table>
| De samlade ved för att göra upp en | elda | 90 | brasad
| Hon köpte halstabletter då hon hade ont i | halsen | 100 |
| Maten var för varm för att | ätas | 100 |
| Brandkåren försökte släcka | elden | 80 | branden
| Ordningen bestämdes genom att leka sten, sax | påse | 90 | yxa
| Lucia har en krona på | huvudet | 100 |
| Till Märta skrev läkaren ut ett | recept | 90 | piller
| Hovslagaren kom för att sko | hästen | 90 | hovarna

Note. Most of the sentences were translated from the completion norms of 329 sentence contexts by Bloom & Fischler (1980). Some sentences had to be adapted to fit Swedish completion norms of sentence contexts.

* The predictability states how many of the participants completed the sentences with the expected word.
Appendix. The stimulus sentences in list 2 of the Hayling task, the words produced by the participants, and the predictability of the sentences based on the produced words. N=10.

<table>
<thead>
<tr>
<th>Sentences</th>
<th>Word produced</th>
<th>Predictability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bosse tappade upp ett varmt</td>
<td>bad</td>
<td>100</td>
</tr>
<tr>
<td>Efter jässning sattes degen in i</td>
<td>ugnen</td>
<td>100</td>
</tr>
<tr>
<td>Hon gick till frisören för att färgra</td>
<td>håret</td>
<td>100</td>
</tr>
<tr>
<td>Jonas fångade bollen med sina</td>
<td>händar</td>
<td>100</td>
</tr>
<tr>
<td>Utan karta kan man lätt gå</td>
<td>vilse</td>
<td>100</td>
</tr>
<tr>
<td>Karin vaknade när väckarklockan</td>
<td>ringde</td>
<td>100</td>
</tr>
<tr>
<td>På biografen visades ett flertal</td>
<td>filmer</td>
<td>100</td>
</tr>
<tr>
<td>Paret köpte ett rött hus med vita</td>
<td>knutar</td>
<td>100</td>
</tr>
<tr>
<td>På stranden byggde Jonas ett slott av</td>
<td>sand</td>
<td>100</td>
</tr>
<tr>
<td>Enligt fartkameran körde hon alldeles för</td>
<td>fort</td>
<td>100</td>
</tr>
<tr>
<td>På natten är det mörkt på dagen är det</td>
<td>ljust</td>
<td>100</td>
</tr>
<tr>
<td>Glaset gick i tusen</td>
<td>bitar</td>
<td>100</td>
</tr>
<tr>
<td>Solen går upp i öst och ner i</td>
<td>väst</td>
<td>90</td>
</tr>
<tr>
<td>På julafont får man paket av</td>
<td>tomten</td>
<td>100</td>
</tr>
<tr>
<td>Damen blev rädd när bäkten slog</td>
<td>ner</td>
<td>90</td>
</tr>
<tr>
<td>Han sprang så länge benen</td>
<td>orkade</td>
<td>100</td>
</tr>
<tr>
<td>Hon gick till optikern för att skaffa nya</td>
<td>glasögon</td>
<td>80</td>
</tr>
<tr>
<td>Svante skrapade maten från sin</td>
<td>tallrik</td>
<td>100</td>
</tr>
<tr>
<td>På hösten faller löven av</td>
<td>träden</td>
<td>90</td>
</tr>
<tr>
<td>Den nyköpta tavlan hängdes på</td>
<td>väggen</td>
<td>100</td>
</tr>
</tbody>
</table>
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