The Feasibility of the Speech Intelligibility Index in the Clinical Hearing Care

BACHELOR THESIS

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The Feasibility of the Speech Intelligibility Index in the Clinical Hearing Care

Möjligheten för tillämpandet av taluppfattbarhetsindexet i den kliniska hörselvården

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Abstract

Hearing-impaired individuals that use hearing aids often experience problems when exposed to daily situations in life. The different environments include for example classrooms, offices and public areas. For the hearing impaired, the correct adjustments of the hearing aids are of great importance. For these settings to be proper, a measurement called the Speech Intelligibility Index (SII), is questioned to be implemented in the clinical hearing care. To answer this question of issue whether feasibility lay in the implementation of SII in the clinical hearing care with the interface of hearing aids, a literature study ordered by the Hearing- & Balance Clinic (H&B) at Karolinska University Hospital situated at Rosenlund Hospital, was initiated. The focus of the study was primarily held in concern of SII as a hearing aid validation measurement and later extended to SII as a room acoustic measurement disregarding the effect of hearing aids. The result of the study showed that the use of SII in the clinical hearing care is troubled and further that the implementation as a room acoustic measurement is probable but has to be additionally investigated.

Abstrakt

## Contents

1 Introduction 1
   1.1 Purpose .......................... 1
   1.2 Goal .................................. 1
   1.3 Scope of Study ......................... 2

2 Background 3
   2.1 Sound .................................. 3
   2.2 The Effects of Hearing Impairment ..... 3
   2.3 Measures of Speech Intelligibility ..... 4
       2.3.1 Technical Methods .................. 4
       2.3.2 AI ................................ 5
       2.3.3 STI .................................. 5
       2.3.4 RASTI ................................. 5
       2.3.5 SII .................................. 6
   2.4 Room Acoustic Measurements .......... 7
       2.4.1 STIPA ............................... 7

3 Materials and Method 8
   3.1 Literature Study ....................... 8
   3.2 Interviews ............................. 8

4 Results 9
   4.1 Literature Study ....................... 9
   4.2 Interviews ............................. 9
   4.3 Room Acoustic Aspect .................. 10

5 Discussion 11
   5.1 Project Model and Chosen Databases 11
   5.2 Obtained Results ....................... 11
       5.2.1 Literature Study .................. 11
       5.2.2 Interviews .......................... 12
   5.3 SII as a Room Acoustic Measurement 13
   5.4 Reflection on the Initial Goal ....... 13
   5.5 Future of SII .......................... 14

6 Conclusion 15

References 16

A Appendices
   A.1 Search Procedure
   A.2 Search Result on SII
1 Introduction

According to the Swedish National Association for Hearing Impaired, HRF, there are about 1.4 million people in Sweden suffering from hearing loss. With impaired hearing means that the auditory system is damaged to a level that the person can not hear a specific sound level at a particular sound frequency. Of the hearing impaired 1.4 million Swedes, about 455 000 take use of hearing aids. This figure is about half of the hearing impaired Swedes that would benefit of a usage, thus 700 000 individuals [1].

When a hearing aid is tested, it is adapted to the audiogram of the impaired, that is measured by an audiologist and contains the frequencies in which the person’s hearing differs from the normal. The apparatus is corrected to benefit the person’s specific hearing issue as well as for anatomical comfort. Testing of hearing aids occurs most often in a hearing clinic where the acoustic environment is fairly quiet, that is, that the background noise is low, hence it is relatively quiet in the room where the settings are made. In the everyday environment, the situation is not the same.

The measurement Speech Intelligibility Index (SII) helps determining the perception of speech for an individual. From the supervisors point of view a possibility for SII to act as a measurement method in the clinical hearing care by providing relevant results in the suitability of aids for a hearing impaired was regarded as a possibility and hence a study of the research is needed and initiated.

1.1 Purpose

In order to determine whether the SII was a reasonable measurement to implement in the clinical hearing care the project’s objectives and the client’s, the Hearing- & Balance Clinic (H&B) at Karolinska University Hospital situated at Rosenlund Hospital, desire was to investigate the question of issue in a literature study. The long term purpose of the study was to investigate the stated question of issue in order to provide results that could be helpful in the possible forthcoming research of the implementation of SII in the clinical hearing care. The possible longterm results were assigned due to the fact that SII might have the possibility to act as a measurement when adaption of hearing aids to hearing impaired requirements and different hearing situations. The feasibility of wheter SII could act as a room acoustic measurement when evaluating different hearing environments was also questioned since a measurement in that certain area never has been properly investigated from hearing impaireds’ point of view.

1.2 Goal

The goal of the study was to: Determine the Feasibility of the Speech Intelligibility Index (SII) Measurement in the Clinical Hearing Care as well as a Room Acoustic Measurement.
1.3 Scope of Study

The hearing care is a wide field. Additionally, the study was focused on the clinical hearing care from both hearing aids’ and hearing situations’ perspective. This includes the adaption of hearing instruments to an individual as well as adjustments of room fitting for the best possible noise reduction.

The primary focus was held on a literature study and information seeking about the SII measurement, and its evaluation of the clinical implementation while the measurement of the SII with the technologies at the H&B was regarded in second hand.

Moreover, the study of SII as a room acoustic measurement when validating different environments was done when spread results stated in the results section were encountered.
2 Background

2.1 Sound

Sound consists of mechanical waves that oscillates through air and other materials. The waves consists of different frequencies that reaches the ear and is perceived differently. Sound is measured with the logarithmic scale decibel (dB) where 0 dB is the standard reference value. Sound and speech that are located in the lower decibel range is inferior in loudness compared to higher sounds. More, the so called tweeter is built up of high frequencies and the base consists of low frequencies. The range of frequencies are divided into 24 frequency bands, so called critical bands [2].

2.2 The Effects of Hearing Impairment

Hearing loss is usually graded as mild, moderate or severe. Regardless of the extent of hearing damage the sound most often becomes weaker and blury to the sufferer and sometimes different frequencies can alloy and consequently sound fields might be missed. More, the sound becomes distorted and it is usually difficult to distinguish different sounds from one another. The most tangible consequence is that it becomes difficult to understand speech. Even a slight hearing loss affects the ability to hear and converse. The perception of what is said does not only include what is said but also how something is spoken. The tone of voice, rhythm and tempo of speech provides important signals, and a hearing loss makes such nuances become more difficult to separate from each other. Additionally, for a hearing impaired individual the frequency and time resolution may be inferior compared to normal hearing and ones dynamic range is affected and consequently loud sounds may be perceived as even stronger and weak sound might not be audible at all [3].

Hearing aids most often helps out in the daily life for a hearing impaired. Especially when the hearing aid is individually tailored to an individuals ear, life situation and different listening needs. Hearing aids might for instance handle problems with dynamic range compressions, when loud sound levels are decreased and quiet are amplified, limits of hearing and time resolution, so that dynamic variation may be detected which further, increases the ability for a hearing impaireds’ hearing to be improved.

Even though hearing aids are very helpful, they have limitations such as nonlinearity. The devices amplify sounds, but cannot reproduce the so called ”auditory sharpness”, the ability to perceive sound nuances and assort neither audio and automatically differentiate background noise from speech or other important information. Instead, for a hearing impaired ear all sound float together.

Directional microphones and programs that suppresses background noise can help, but does not solve issues that a hearing impaired experiences. People with hearing aids therefore often need access to an inductive loop or similar communications,
that create better conditions for hearing in daily life [4].

2.3 Measures of Speech Intelligibility

The evaluation of sound environments has, over the years, been made in various ways and is particularly important for the hearing impaired. Speech intelligibility measurements are made in order to determine how much of a spoken message that can be understood by an individual in different environmental conditions including travelling situations such as subways and public arenas, for instance lecture halls. Moreover, the American National Standards Institute (ANSI) initially standardized the measure of speech intelligibility due to the importance of verification of electronic acoustic sound systems for emergency purposes [5]. The measurement of speech intelligibility can be made in a vast variety of ways where multiple methods have been included in the sound system equipment standard IEC 60268-16. ANSI has also standardized minimums of speech intelligibility, how much of spoken sound that can be understood by a listener, in different environments that are included in the standard for fire detection alarms, ISO 7240 for instance. Thus, if an alarm system is tested for a speech intelligibility index below an accepted level for a particular method, the alarm system is not allowed [5]. These environments are further explained in subsection 2.3.5.

According to HRF some methods to measure speech intelligibility are based on letting a trained human speaker read a collection of sentences to a group of people and let these people, individually, declare how much of the sentences read out loud they perceived [1]. The statistical analysis of a person’s believed understanding are represented as a percentage of the correct original sentences. There are some standardized methods to measure speech intelligibility based on this procedure, for example Speech Reception Threshold (SRT) which measures the difference between a selection of hearing-aids. The principle of such measurement are often the most reliable and brings the most truthful results of a person’s speech intelligibility. However, evaluations like these are extremely time consuming and therefore expensive. Thus, technical methods have been developed in order to reply to requirements such as taking varying parameters\(^1\) into account [1].

2.3.1 Technical Methods

The category of technical, also called machine-based, methods take multiple important aspects when dealing with speech intelligibility into account [2]:

- Speech level
- Background noise level
- Reflections and Reverberation

\(^1\)Example of varying parameters are type of room (absorbing walls or not), different types of hearing impairments, different levels of hearing impairments and different types of noise among others
• Psychoacoustic effects (masking effects)

Over the last half century several machine-based methods have been developed and can be divided into two categories, reverberation analysis that are based on analysis of the speech intelligibility, hence when echoes are regarded, and signal-to-noise methods that are used as measurements in the area of speech intelligibility. Only the latter is of interest in this study due to that SII is regarded as a signal-to-noise measurement [2].

The signal-to-noise measurements are:

• AI - Articulation Index
• STI - Speech Transmission Index
• RASTI - Rapid Speech Transmission Index
• SII - Speech Intelligibility Index

2.3.2 AI

During the early 1940s the physicist Harvey Fletcher at Bell Telephone Laboratories developed a measurement of the intelligibility of speech in order to increase the quality of telephone calls. The introduced calculation model, Articulation Index (AI), states that response of speech systems may be separated into twenty bands of frequencies, where every band contributes with information about the intelligibility of the system. Signal-to-noise ratios, SNR, are computed for each band and later weighted and combined to yield a score of intelligibility. The score has a range between 0 and 1 where 0 indicates that the system has no intelligibility at all and 1 is the contradiction.

AI has been implemented as a tool in the evaluation of tested hearing aids for patients with hearing loss. However, the AI is not ideal. For example, it only takes stationary noise into account while in daily environments the sound can almost always be regarded as fluctuating.

2.3.3 STI

Speech Transmission Index (STI) was developed in the 1970s and use the theory that speech can be described as waveforms that consist of low-frequency signals. When testing with STI a speech-like signal, that is a result of a complex amplitude modulation scheme, is regarded. When the signal is received at the end of the system its depth of modulation is compared to the original test signal in each of the frequency bands. As well as AI, STI is ranked from 0 being the worst, to 1 being the best possible output.

2.3.4 RASTI

The Rapid Speech Transmission Index (RASTI) or sometimes referred to as the Room Acoustics Speech Transmission Index was initially developed to provide
a less complex test, compared to STI, to measure speech intelligibility. Hence it implements the same core principles as STI but only considers bands with average frequencies of 500 Hz and 2 kHz. Due to the limitation RASTI is a quick measurement that can be used in both installed sound systems and acoustically. Though, due to the simplification in contrast to STI, RASTI only test two different bands of frequencies and therefore many systems receives an incorrect performance index, mostly too optimistic. Therefore, RASTI is almost never used today.

2.3.5 SII

In recent years, a measurement called Speech Intelligibility Index has been developed. The measure has influences of AI and STI and should function to evaluate hearing and intelligibility of speech in a way that is adaptable to real acoustic environments. The SII was standardized in the ANSI 1997 and four measurement procedures, in descending order of accuracy, are to be chosen from:

- Critical band (21 bands)
- One-third octave band (18 bands)
- Equally-contributing critical band (17 bands)
- Octave band (6 bands)

The SII value ranges from 0 to 1 and can be computed by the following equation:

\[
SII = \sum_{i=1}^{n} I_i A_i
\]

In the equation, the variable \( n \) corresponds to the number of frequency bands that are used. There are different types of qualities of information that are contained in each and every frequency band and the qualities of the carried information are determined by the values of the variables \( I \) and \( A \). The variable \( I \) corresponds to the importance of a given frequency band and the variable \( A \) corresponds to the audibility of a given frequency band. Generally, these variables are representatives for the information that is carried in the individual frequency bands. A higher index value corresponds to a superior level of intelligibility and vice versa [6].

Today SII is the most developed machine-based measurement and most often delivers trustful results. The measure has improved resolution in comparison to the others, especially in the critical band procedure. Moreover, reverberations, noise and distortion are included in the calculation of SII, the modulation transfer function which is the core of SII.

The disadvantages of SII include the handling of late-arriving reflections such as echoes. If compression and/or limiting is taken into consideration in the environment SII often generates a decreased score compared to reality. It also ignores frequencies below 100 Hz and may therefore miss low-frequency masking sources. Additionally, SII does only take linear sound into deliberation.
SII has not been adequately evaluated in order to draw conclusions in the aspect of clinical situations. Hence an entry in the clinical hearing care in Sweden has only been done in minor. Mentioned by experts on the area [7], SII in adapted forms has only been introduced as a limited measurement to verify hearing aids under extremely modest conditions. These introductions have developed in hearing aid fitting methods such as NAL-NL1, that are examples of test done when fitting hearing aids. However, the environments to take in consideration in this study are regarded as complex due to the fluctuating noise that is to be taken into account.

2.4 Room Acoustic Measurements

Speech intelligibility can also be measured and analyzed in room acoustic environments and is specially of interest when evaluating public places. In these cases the most important parameter to take into account is, according to Great Britain’s National Deaf Children’s Society (NDCS) [7], reverberation. Moreover, when the initial studies are to be set-up in this area of interest there is no high priority criteria to implement the use of hearing aids at the very beginning. Though, in the future the aspect of including hearing aids could be regarded as interesting.

2.4.1 STIPA

One introduced measurement when validations of room acoustics are made is Speech Transmission Index Public Address (STIPA). This measurement is somewhat expensive due to that it is time consuming since it requires 98 parameters when calculated. More, the system considered has to be linear and synchronous. Though, in the relatively new born field of studies concerning speech intelligibility of room acoustic, this method is the most implemented one. This partly due to the fact that no other measurement has been properly introduced in the area and that the few other measurements that are available are more expensive or does not bring as trustful results as STIPA.
3 Materials and Method

3.1 Literature Study

After the start-up meeting with the client and initial literature study, a course in acoustics and audiology was attended. The course was distributed by H&B and given by a speech therapist as well as two engineers specialized in hearing, from the Karolinska University Hospital. To further answer the question of issue, the project in the area mainly consisted of literature studies in the database PubMed and was later extended with the database Scopus. In PubMed the search focus was on SII as a potential measurement implementation in the clinical hearing care while the search in Scopus was concentrated to the use of SII in room acoustics and future applications in the area. The search procedure is included in appendix 1.

After the initial search (search 10) the hits found were closer investigated. 14 of the articles found were regarded as more interesting compared to the others and was therefore sent to H&B for validation. Moreover, 8 of the 14 articles were, from H&B’s perspective, declared as suitable and contributory to answer the question of issue. Additionally, further studies were held with focus on SII as a complementary measurement for speech perception in a room and practical situations when SII has been implemented in the clinical hearing care. These searches were done in search 11 to search 19.

After discussion with the supervisors, reflection and analysis of the results found on the implementation of SII in the clinical hearing care with regard to hearing aids, the focus was modified from measurements in situations when regarding SII as a room acoustic measurement without the aspect of hearing aids. As mentioned, the database Scopus was chosen for the study.

3.2 Interviews

Interviews with the hearing engineering professors and scientists within the are of intelligibility of speech Karolina Smeds, Martin Dahlquist and Traci Flynn were held via Skype and cell phone calls. They contributed with information, answers and their perspectives of the question of issue in order to broaden the information gathering.

The supervisors at H&B were available via e-mail and physical meetings to answer questions throughout the study.
4 Results

4.1 Literature Study

The search did not produce any positive verification of the feasibility in the implementation of SII as a validation tool in the clinical hearing care, the most clear example of this is stated by Humes et al. [5]. Alongside, studies initiated on diverse areas have been done. A couple of extended SII models have been analyzed as alternatives to SII [8] [9]. These extended versions of SII are diversified in the aspects of positive or negative results.

Research that contradicts these verifications shows that SII, in its general form, could possibly be introduced in the clinical hearing care, are a few hence of great importance. Stiles et al. describes how SII was regarded as more sensitive compared to other measurements, for instance Pure-Tone Averaging (PTA) which is a behavioral test used to measure hearing sensitivity [10].

The final search procedure and the articles found are located in the appendices. The articles that contributed most to answer whether SII could be used in the clinical hearing care are found in the reference list. These articles gave relevant and helpful result for the concerned subject area.

4.2 Interviews

According to the interview objects the SII has a minor possibility of implementation as a validation measurement in clinical use. Though, the interview objects mentioned that different varieties of SII has been developed and are used today in the hearing care. Some of those different forms are stated below. The most significant inputs from Smeds and Dahlquist are listed below [11]:

- SII does not take important parameters into account for instance fluctuating noise and random reverberation.
- SII as a general measurement, hence when no regard to hearing aids are taken into consideration, is already used in the hearing care during production and testing of technical hearing instruments such as inductive loops.
- There are different versions of SII such as short-time SII and coherence SII (cSII) that are complements to the standard SII.

More, the most vital notes from Flynn are listed below [12]:

- SII does not take important parameters such as nonlinearity and sound wave compression into account.
- SII needs to be supplementary widespread and there is a requirement for more research in the area in order to draw extensive conclusions in clinical hearing care situations.
- There is a lack of technical competence between care personnel.
A measurement program that has its core in SII, Sertoma Hearing Aid Recycling Program (SHARP) has an improved opportunity of usage in the area of interest [13].

Flynn accounted for the measurement program SHARP stated above. SHARP uses SII in its calculations and provides an estimate of a patient's hearing impairment by inserting an assemblage of parameters such as the patient's audiogram. She mentioned that SHARP could be used in order to evaluate a patient's hearing impairment but that it is only in a certain environment when given parameters are taken in concern.

Hence, the SII measurement does not seem to have any impact when evaluating hearing impairments in the clinical hearing care. To clarify, the study showed that the area of SII as a measurement in the clinical hearing care is a new area of interest and further studies has to be initiated on the measurement. Partly around the general SII as a measurement in the clinical hearing care and partly on extended versions on the measurement.

### 4.3 Room Acoustic Aspect

As stated, NDCS explains that the most important parameter to take into account when evaluating room acoustics is reverberation. Further, the measurement SII takes linear reverberations into consideration and could therefore be used as a tool for evaluating simple room acoustics. Additionally, Scopus contributed with indication that further research should be held within the area of room acoustics in order to draw any conclusions about the use when considering fluctuating noise [14] [15].
5 Discussion

5.1 Project Model and Chosen Databases

The project model of literature studies is generally chosen in situations when an initiated stage of a research ought to be made in order to gather as great information about the specified area as possible before an eventual practical research is initiated. The supervisors at the H&B were in the initial phase of research about the SII and the validation of it in the care of hearing impaired patients. Due to the current stage of the entire research, there is a need for further information gathering before any extensive practical studies can be made by the H&B. Hence, investigating the question of issue through a literature study and widening the information gathering by interviews was due to the stated reasons obvious. Performing a research without any initiated literature study would not be recommended in cases where researchers’ knowledge is limited, which usually is the case when relatively new areas are to be investigated.

The subject relevant database PubMed was chosen due to its medical focus and broad range of articles. Additionally, the database Scopus was chosen in the developed literature study because of its large content covering more subject areas compared to PubMed. This was in order to receive more information about the acoustics of a room. As stated above, the database Scopus was chosen alongside with PubMed at the initiation of the study. Though, after the first ten searches the same search results appeared in both the databases and Scopus was neglected due to the fact that PubMed is regarded as major according to the information need and was well known by the supervisors. Though, as stated above, Scopus was later reclaimed. Neglecting Scopus in the beginning of the study should not have affected the result negatively in any extensive way due to the reasons stated above.

5.2 Obtained Results

As stated in the background, there are some important requirements for measurements and methods to be able to be implemented in the clinical hearing care. SII as a general measurement does not reply to those requirements which implies problems for an eventual implementation in the clinical hearing care. Reasons to why SII is not replying to the requirements are discussed below. Though, mentioned must be that different extended varieties of SII has been developed and some of them are used as tools in the hearing care.

5.2.1 Literature Study

The SII is a measurement model adapted to certain environments and conditions. These conditions include the comfort in listening with hearing aids as well as the limitations methods regarded when adapting a hearing aid to an individual. Moreover, SII is an optimal measurement when studies in environments with constant parameters such as quietness are done. Though, at times noise, especially fluctuating, is added the SII measurement meets problems. Above all SII meets problems
when connected with reverberation and room acoustics due to the fact that a distortion factor will arise which will result in incorrect installations of the hearing aids. Throughout the articles found the different authors have provided methods where multiple types of processing of signals are used, such as signal peak-clipping and signal center-clipping. The fact that different versions of SII have been developed indicates that the general SII measurement has flaws. This partly due to the facts that SII is a rough measurement, mathematically flat and does not take varying parameters such as fluctuating noise into account. Though, an important observation is that the presented versions of SII gives different results through different studies made. One example is presented by Humes et al. who states that other methods based on linear-regression statistical analysis proves better results than the SII [5]. Humes et al. explains further the difficulties that the SII would meet if directly implemented in the clinical hearing care mainly because of its mathematical flatness and linear requirements. Besides, there are different correction factors such as age, a hearing impairment may differ as a patient gets older, and that SII needs calibration in order to adapt to patients’ varying ages. The SII does not seem to adapt to non-constant parameters which should be essential in order for an eventual implementation in the clinical hearing care. While Humes et al. describes the flaws of SII, Stiles et al. provide results where SII shows significantly better results in evaluating hearing impaired children compared to PTA [10]. This even though PTA has already been implemented in the clinical hearing care in validation of hearing aids. 

Additionally, hearing aids are vigorously nonlinear which may cause a hassle when applying the SII measurement since the mathematics for such conditions are too complicated for the required SII parameters. Moreover, SII would have problem when regarding echoes of a room because echoes contribute to increased energy in certain frequencies and SII could categorize those as an increase in the hearing aid’s reinforcement which would possibly lead to incorrect results. This can be clarified by the example of a classroom where the walls are usually lacking in absorbing sound waves. This implies problems in the presence of fluctuating noise since the noise signals could reflect on walls of a room back into the amplifying hearing aid. Thus, this would result in amplified noise which is vastly unfavourable.

5.2.2 Interviews

The advantages of the SII according to Smeds and Dahlquist and the reasons why it is used today in hearing care are the possibilities of identifying different sound environments. For example, based on an analysis with SII one may detect situations when there is a requirement for directional microphone, noise reduction and/or inductive loop. Hence, an introduction in the hearing care, though not in the clinical hearing care, have been made and therefore SII might not have to be regarded as extremely unfamiliar.

In the interview with Flynn, the forecast of SII was not particularly optimistic. She mentioned that if SII ought to be used in the clinical hearing care with respect
to hearing aids, every individual’s audiogram needs to be used in the assessments. An average of every single individual in a specific environment would not be representative for each hearing impairment in each hearing environment due to all the varying parameters that could imply individuals with hearing impairment to still have problems with the speech intelligibility. As stated in the results, Flynn also mentioned SHARP which has the advantage of its recyclable property, ability to be used for individuals and its less complex user interface as well as not being overly technically complex which is beneficial in the clinical hearing care due to the generally limited technical competence among care personnel. Even though SHARP might seem as good measuring program in the assessment of hearing impairments, it still only gives an estimated evaluation of a hearing impairment in a given situation which means it does not deal with varying parameters.

The results obtained from the two interviews was not dramatically surprising. This mostly due to that the information found in the literature study initiated at the time had brought similar results. Though, there was still information gaps, regarding the disadvantages of SII, to be filled before the interviews.

5.3 SII as a Room Acoustic Measurement

When the search in Scopus was done, the implementation of SII as a room acoustic measurement, without the use of hearing aids, was regarded. According to Larm and Valtteri, the discrepancy between current measurements in rooms acoustics, such as STI, and the SII measurement is not vast [11]. This provides evidence that SII could be used as a room acoustic measurement. Moreover, since SII is influenced by AI, STI and STIPA that are currently used as room acoustic measurements, the usage of the SII to evaluate different hearing environments when not taking hearing aids into consideration is likely.

Though, since the area of room acoustics use lacks in information in the aspects of the important parameters such as reverberation and fluctuating noise, further investigations have to be made. Due to the fact that SII does not differ grandly from the already implemented room acoustic measurement STI the use of SII as a measurement in that particular area would likely be positive.

5.4 Reflection on the Initial Goal

The goal for the study was to: Determine the Feasibility of the Speech Intelligibility Index (SII) Measurement in the Clinical Hearing Care as well as a Room Acoustic Measurement. The deliberate definition of feasibility would be if SII ought to be used when fittings of hearing aids in concern of cancellation of fluctuating noise is done. Hence, the question lies whether SII could be used as a measurement taken into consideration in the already complex mathematical calculation of noise reduction in the clinical hearing care.

Due to the results found during the literature study as well as during the interviews held with the experts on the research area, the general SII was regarded
as too simple, in the mathematical aspect, to be implemented in the concerned environments. The results received from the literature study as well as during the interviews showed that the feasibility of implementation of the general SII in order to evaluate hearing impairments, is not ideal at the moment. This is due to the fact that the general equation of SII only considers stationary, linear and non-fluctuating noise and hence reduction of fluctuating noise cannot be made since it is never regarded as an explicit parameter in the stated equation. Though, as reflected above, the introduction of the general SII as a room acoustic measurement would likely be regarded as feasible. Moreover, the feasibility of other extended versions of SII if parameters of fluctuating noise is included in the original equation, might be regarded as having a feasibility of implementation in the clinical hearing care.

5.5 Future of SII

After the introduction of AI as a measurement for speech intelligibility, STI, RASTI and SII are some of the SNR methods and measurements that have been developed. Further, continued measurements that has its core in SII have been developed and adapted to different required conditions. Among these measurements that are stated in the result section, Smeds and Dahlqvist mentioned some.

- Coherence Speech Intelligibility Index (cSII) has been developed from SII in order to investigate the relation between speech quality and speech intelligibility in researches where speech quality has been regarded.

- Short-time SII is a helpful niched measurement when a simpler version of SII is required. A less complex version in turn, contributed with a lower cost. In this form less parameters are taken into consideration compared to the original form of SII.

- One of the extended SII measures was validated Speech Reception Threshold (SRT) in order to experiment with non stationary noise conditions.

The mentioned alternative forms of SII shows that the implementation of another complementary form of SII can be developed if the required parameters and the correct knowledge among engineers can be found. Hence, to be able to adapt the SII measurement to the clinical hearing care’s requirements and needs when connecting hearing aids, extended versions have to be made. Due to the lack of input parameters in the original form of SII, further complex models of SII including fluctuating noise and the impact of hearing aids have to be taken into the calculation. If more studies on the area can be done and more information is gathered this seems to be a possibility in the future. To sum up, more studies and evaluations need to be made to be able to regard this implementation as realistic and applicable in individual hearing aid corrections. If this could be the case a more comfortable level of gain and speech perception for a hearing impaired using hearing aids are expected.
6 Conclusion

Even if there are several areas of use regarding the SII, it does not seem to have any impact when evaluating hearing impairments with regards to varying parameters in the clinical hearing care. The feasibility of the general form of SII in the clinical hearing care is according to obtained results vastly limited. Though, future research about extended versions as well as different perspectives in hearing care ought to be made.
References


## A Appendices

### A.1 Search Procedure

<table>
<thead>
<tr>
<th>Search</th>
<th>Search keywords</th>
<th>Number of hits</th>
<th>Comments</th>
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<td>14</td>
<td>7 relevant articles. Narrowed down search by adding “hearing aid”.</td>
</tr>
<tr>
<td>2</td>
<td>SII AND acoustics AND hearing aid</td>
<td>5</td>
<td>5 relevant articles but all of them were included in search #1.</td>
</tr>
<tr>
<td>3</td>
<td>SII AND acoustics AND hearing care</td>
<td>1</td>
<td>No new articles found.</td>
</tr>
<tr>
<td>4</td>
<td>SII AND acoustics AND hearing aid AND fluctuating noise</td>
<td>3</td>
<td>3 relevant recommended citations. Results found from alternative search.</td>
</tr>
<tr>
<td>5</td>
<td>SII AND fluctuating noise</td>
<td>3</td>
<td>The same articles as from search #4.</td>
</tr>
<tr>
<td>6</td>
<td>SII AND fluctuating noise AND hearing aid</td>
<td>0</td>
<td>Widen search by removing “SII”.</td>
</tr>
<tr>
<td>7</td>
<td>fluctuating noise AND hearing aid</td>
<td>27</td>
<td>9 relevant articles.</td>
</tr>
<tr>
<td>8</td>
<td>fluctuating noise AND hearing aid AND hearing care</td>
<td>2</td>
<td>No new articles found. Widen search by removing “hearing aid”.</td>
</tr>
<tr>
<td>9</td>
<td>fluctuating noise AND hearing care</td>
<td>8</td>
<td>No new articles found. Exchanging search keyword “hearing care” for “hearing impairment”</td>
</tr>
<tr>
<td>10</td>
<td>fluctuating noise AND hearing impairment</td>
<td>61</td>
<td>14 relevant articles found. Articles sent to H&amp;B.</td>
</tr>
<tr>
<td>11</td>
<td>SII AND speech perception AND practical</td>
<td>2</td>
<td>1 relevant. Found the key search word “SPIN”.</td>
</tr>
<tr>
<td>12</td>
<td>(speech intelligibility index OR SII) AND speech perception AND practical</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>SII AND speech perception in noise</td>
<td>35</td>
<td>8 new relevant articles found.</td>
</tr>
<tr>
<td>14</td>
<td>(speech intelligibility index OR SII) AND speech perception in noise</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>SII AND speech-reception performance in noise</td>
<td>3</td>
<td>0 relevant articles.</td>
</tr>
<tr>
<td>Search</td>
<td>Search keywords</td>
<td>Number of hits</td>
<td>Comments</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------------------------------------------</td>
<td>----------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>1</td>
<td>(SII OR Speech Intelligibility Index) AND room AND acoustic</td>
<td>133</td>
<td>1 relevant article.</td>
</tr>
<tr>
<td>2</td>
<td>(SII OR Speech Intelligibility Index) AND classroom AND acoustic</td>
<td>39</td>
<td>Narrowed version of search #1. No new relevant articles.</td>
</tr>
<tr>
<td>3</td>
<td>(SII OR Speech Intelligibility Index) AND classroom AND acoustic AND noise</td>
<td>33</td>
<td>No new relevant articles.</td>
</tr>
<tr>
<td>4</td>
<td>(SII OR Speech Intelligibility Index) AND classroom AND acoustic AND fluctuating noise</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Search in PubMed.

Table 2: Search in Scopus. During the whole search, the specific setting to only search for search keywords in article title, abstract or article keywords was used.
A.2 Search Result on SII


Smeds, Karolina, Florian Wolters, and Martin Rung. ”Estimation of Signal-to-Noise Ratios in Realistic Sound Scenarios.” Journal of the American Academy of


Köbler, Susanne, and Arne Leijon. "Noise analysis of real-life listening situations..."


