

The effect of noise-induced hearing loss on the perception of Dutch consonants in different types of noise

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Abstract

In this study the effect of noise-induced hearing loss on Dutch consonant perception in different types of background noise is investigated. There is quite a lot of research about consonant perception in background noise and also some on that topic with hearing-impaired participants, but no research has been done on noise-induced hearing loss, which is an interesting type of hearing loss in this particular field of study, because of its spectral frequency properties. In this experiment 10 normal hearing people and three hearing-impaired people of ages 25 - 39 listened to 24 consonants in a clean condition and in three noise type conditions: a competing speaker, modulated speech-shaped noise and speech-shaped noise. There is no difference in performance of consonant identification between normal hearing and hearing-impaired people. The effect of noise type was significant, with modulated speech-shaped noise being the most difficult and competing speaker the easiest condition for consonant perception. No interaction between these factors was found, but different groups of consonants did yield differences in performance of consonant identification. The type of background noise therefore matters in consonant perception and some consonants are more affected than others, but there is no effect of hearing ability with noise-induced hearing loss.

Introduction

When we listen to speech, the sounds we hear are often not completely devoid of background noise. People communicate whether this noise is present or not and with the varying kinds of noise that can be present in conversations, such as conversations in the background, traffic or loud noises on the workplace, the perception of speech will be negatively affected (Broersma & Scharenborg, 2010; Cooke, 2006; Cooke & Scharenborg, 2008; Cooke et al., 2010; Festen & Plomp, 1990; Garcia Lecumberri et al., 2008). Not only is the type of noise a factor in this matter; the properties of speech, such as frequency and intensity, are also important in investigating differences in perception in noise. With these properties differing in value, the individual sounds that make up the speech also play a role in the way they are perceived in noise (Miller & Nicely, 1955; Wang & Bilger, 1973; Garcia Lecumberri et al., 2008; Cooke & Scharenborg, 2008; Cooke et al., 2010). On top of that, factors related to the listener are relevant as well. When the listener suffers from hearing loss, investigating speech perception is more complicated, especially because different causes of hearing loss lead to different types of abilities to hear sounds at certain frequencies (Gelfand et al., 1986; Maniwa et al., 2008; Sher & Owens, 1979). This affects the ability of the listener to understand speech, with or without background noise. The number of factors that can be relevant in perception of speech is very high, so research in this area can be very useful. In this paper the effect of different types of background noise on consonant perception for normal hearing people and hearing-impaired people will be investigated.

Hearing loss

Types of hearing loss

Hearing impairment is a very common impairment: 10 % of people in the US have a hearing impairment to such a degree that it affects their communication in everyday life, which makes it the most common sensory disorder (Lustig, 2016). I have not been able to find data on this subject about the Netherlands, but it is likely that these numbers are similar for the population of the Netherlands. Hence, research on this topic seems very important. Hearing impairment is divided into categories based on the parts of the hearing pathway that are affected. Generally, there are three types of hearing loss: conductive, sensorineural and mixed (Lustig, 2016). Conductive hearing loss occurs when sound is blocked from reaching the inner ear by an obstruction in the outer ear, the middle ear or the eardrum. Sensorineural hearing loss

occurs when sound is able to reach the sensory nerve, but the nerve does not translate the sound into impulses or it does not carry on the impulses to the brain. This is the most common form of hearing loss. Mixed loss occurs when both conductive and sensorineural loss are involved. Conductive loss can be treated by removing or fixing the obstruction of the sound, but sensorineural loss is more often not reversible.

The most common causes of sensorineural hearing loss are noise exposure, age and ear infections. Noise exposure can account for sudden or gradual sensorineural hearing loss, depending on the duration of exposure and the loudness of the sound. Long-term exposure to sound is the most prominent cause of noise-induced hearing loss. Age-related hearing loss (presbycusis) is very common as well. The hearing loss process starts at about 50 years old and progressively increases with age. Over one third of people over 65 and over half of those over 75 suffer from this kind of hearing loss. Ear infections on the other hand occur mainly in children and can cause temporary mild or moderate hearing loss. Most children regain normal hearing within weeks, but children with recurring ear infections are at risk of permanent hearing loss. However, this type of hearing loss is not as common as noise-induced or age-related hearing loss. Other causes of sensorineural hearing loss are genetics (inherited hearing loss), drugs that can damage the ear (ototoxic drugs), infections, disorders and tumors.

These different causes of hearing loss have different effects on the perception of sounds at specific frequencies. For instance, age-related hearing loss typically starts at the highest sound frequencies and gradually spreads to lower frequencies while the hearing in higher frequencies deteriorates even more. However, that is not the case for noise-induced hearing loss. In hearing loss caused by noise exposure, the frequency spectrum of an impaired listener typically shows a notch at around 4000 Hz. Initially, mostly that frequency is affected, but when more hearing loss is acquired, in later stages the hearing loss can spread to 3000 and 6000 Hz (ANSI, 1996; Chen & Tsai, 2003; Taylor et al., 1965). It is in these frequencies that consonants have a lot of information necessary for their correct identification and that is why the perception of these sounds is different for different types of hearing loss.

Earlier research on hearing loss

The effect of different types of hearing loss has been investigated in earlier research about consonant identification in noise. Festen & Plomp (1990) found that for normal hearing listeners the perception of the target signal differed

in different noise conditions, but participants with moderate sensorineural hearing loss (with different causes) did not show differences in perception in different noise conditions. Research on consonant identification with hearing-impaired participants has shown that in this group of participants the least frequent confusions between consonants in noise happen with sibilants, and the most frequent confusions happen with fricatives that are not sibilants (especially in final position), and plosives (Gelfand et al., 1986; Maniwa et al., 2008; Sher & Owens, 1979). Nasality also proves to be a robust feature in noise as well as voicing (Gelfand et al., 1986; Maniwa et al., 2008). In Maniwa et al. (2008) it is shown that more spectral energy at higher frequency regions and strength of the properties of the sounds of fricatives improve the overall intelligibility of those sounds. In Scharenborg et al. (2015) it was investigated if listeners are able to compensate the lower intelligibility of speech caused by hearing loss, with coarticulatory information. This effect of compensation through articulatory cues was investigated for fricative categorization, but it was not found to be significant.

Noise-induced hearing loss

The previously mentioned studies about hearing loss are conducted with participants with different types of hearing loss, but none of these, and very few studies in general, are about noise-induced hearing loss. It seems here that research about specifically participants with noise-induced hearing loss is missing and that's why this article provides research about this type of hearing loss. The lack of research in this area is peculiar, because noise-induced hearing loss is a very common type of hearing loss. It is one of the most recorded occupational disorders in Europe as it amounts to between 7 and 21% of the hearing loss there and it is therefore regarded as a serious health problem in society with economic consequences (Lie et al., 2016). Offshore workers, professional divers (differences in ear pressure), firefighters, railway workers, civil aviation workers, musicians and kindergarten employees have a low risk of acquiring occupational hearing loss. Industrial workers, shipyard workers, construction workers, military workers, farmers and rock/jazz musicians have a moderate risk of acquiring occupational hearing loss. Employees in the music business like music venue workers and DJs are also at a substantial risk of developing noise-induced hearing loss, with average sound levels reaching 96 dB, when long-term exposure of sound above 85 dB can already be harmful (Petrescu, 2008). Causes for noise-induced hearing loss are obviously found in recreational and social settings as well (Petrescu, 2008). For instance, concert attendees have been repeatedly found to acquire hearing damage from loud music, with rock concerts being of the highest risk (Meyer-Bisch, 1996;

Hanson & Fearn, 1975). Similarly, discotheque and club attendance can be very harmful, as it can cause temporary tinnitus and shifts of the hearing intensity threshold around 3000-4000 Hz (Metternich & Brusis, 1999). It has also been estimated that over two decades, from 1980 to 2000, social noise exposure tripled with young people (Smith et al., 2000). Three studies in schools and colleges found that around 40% of listeners of mp3-players listen to music for longer periods of time at a volume higher than 85 dB, concluding that a big part of listeners of mp3-players is at increased risk of developing noise-induced hearing loss (Vogel et al., 2011; Levey, Levey & Fligor, 2011; Levesque et al., 2010). In almost every one of these instances, the hearing loss occurs in both ears. Assymmetric noise-induced hearing loss can also occur and typically does occur in shooting with a rifle or shotgun, which happens both in occupational and recreational settings. Clark & Bohne (1999) argue that this in fact creates such an intense impact noise that a shooter can acquire 1 year's worth of damaging occupational noise exposure in just a few minutes.

The effect of different types of background noise on speech perception

Much research has already been done on the topic of speech perception in background noise, about for instance investigating the effect of signal-to-noise ratio on speech perception (Festen & Plomp, 1990), language of the masker speech and target speech (Cooke et al., 2010) and visual context (Miller & Nicely, 1955). To research the effect of the different types of background noise people deal with in life, the types of background noise used in experiments in this research area are chosen based on the noises people encounter most frequently. The research done in this topic confirms the idea that different kinds of noises have varying effects on the quality of speech perception. Cooke & Scharenborg (2008) investigated consonant identification in a clean condition and six other noise types: competing talker, 3-speaker babble, 8-speaker babble, factory noise, speech-shaped noise and modulated speech-shaped noise. With an SNR of -6 dB, factory noise seemed to be the most difficult background noise to perceive consonants in, because the factory noise used in this experiment had a lot of energy in the frequency range where speech typically resides at.

In most experiments on speech perception in background noise, other types of noise are used than factory noise (Broersma & Scharenborg, 2010; Cooke, 2006; Cooke et al., 2010; Festen & Plomp, 1990; Garcia Lecumberri et

al., 2008). For instance, multi-speaker babble is used in various experiments, but this type of noise is mostly used in experiments in which the focus is on another research topic (e.g., nativeness of language, different/same speaker in masker and hearing of participants). Typically, the types of noise that are used in experiments with the aim to investigate the effect of different noise types in consonant perception are speech-shaped noise, speech-modulated noise and a competing speaker. Those first two noises are energetic maskers, a masker with only noise in the signal, and the latter is an informational masker, of which the signal has additional information on top of the noise itself (Brungart et al. 2001). Between these three noises, speech-shaped noise generally seems to be the best masker in the same SNR between conditions, i.e., the condition with the worst consonant identification scores (Broersma & Scharenborg, 2010; Cooke, 2006; Cooke & Scharenborg, 2008; Cooke et al., 2010; Festen & Plomp, 1990; Garcia Lecumberri et al., 2008). However, there is no significant difference between the performance in speech-modulated noise and competing speaker with the same SNR. The reason for the differences between speech-shaped noise and the other types of noise seems to be in the properties of the spectrum. Speech-shaped noise typically consists of a steady-state kind of noise, while speech-modulated noise and the competing speaker masker offer temporal glimpses of the target signal. In these two maskers the spectrum has temporal modulations in its frequency, which reduce the masking effect at specific points in time and can provide the listener with more information of the target, as stated in an article by Cooke (2006). The same article showed that this effect of temporal modulation was also found for an automatic speech recognition system, in which the proportion of the signal that is glimpsed from the spectrum is a good predictor for the intelligibility of the spectrum.

Similarity of the target and the masker signal

When using speech as a masker, performance in consonant identification is generally better when the properties of the target speech are different from the properties of the speech used in the masker than when these properties are alike (Brungart et al., 2001). Moreover, performance is better when the masker and the target have a different speaker than when they have the same speaker. Identification of consonants is also easier when the gender of the speaker is different from that of the speaker in the masker (Brungart et al., 2001).

Consonants and phonological features

As mentioned earlier, background noise affects the perception of different consonants differently. In a study by Wang & Bilger (1973) on the perceptual cues of consonants in noise, it becomes clear that the difference in perception of consonants in noise can be caused by the differences in the articulatory and phonological features that consonants consist of. A consensus about which features in consonants are transmitted best among the noise conditions, i.e., features of which the most information is perceived through the sound, has not really been reached, as the findings of experiments about this topic differ. The nasality feature is well perceived in noise, as shown in studies by Wang & Bilger (1973) and Miller & Nicely (1955). The voice feature is also shown to be well perceived in these studies, but in a study of Cooke et al. (2010) it is the worst perceived phonological feature. The perception of the place of articulation of a consonant seems to be affected by noise (Miller & Nicely, 1955), especially in the competing speaker masker (Cooke et al., 2010). There seems to be more consensus among studies about consonant perception in noise on the groups of consonants. Sibilants are the best identified consonants across noise conditions (Cooke & Scharenborg, 2008; Cooke et al., 2010; Garcia Lecumberri et al., 2008), especially in speech-shaped noise. Because of the properties of sibilants, this subset of consonants is less sensitive to noise with a speech-shaped spectrum. The frequency of sibilants is high enough that information is perceived through the masking effect. Non-sibilant fricatives are consistently most difficult to identify in both quiet and noise and more specifically /f/, /v/, /ð/ and /θ/ (Cooke & Scharenborg, 2008; Cooke et al., 2010; Garcia Lecumberri et al., 2008). These sounds get confused with one another very often in these experiments.

Research aim

Noise-induced hearing loss is very common in occupational and recreational settings across varying parts in society. Because of that and its typical spectrum, more research on this topic should be conducted, and has been conducted in the experiment described in this article. The effects of different types of consonants, noise-induced hearing loss, different types of background noise, and the interaction effect between the last two factors will be investigated for consonant perception. Therefore, the research question this study aims to answer is: What is the effect of different types of noise on the perception of Dutch consonants in normal hearing people and people with noise-induced hearing loss? In the experiment a hearing test has been conducted, followed by a hearing task. From the participants' results, corresponding

conclusions will be drawn and elaborated upon.

Method

Participants

13 people participated in the experiment and their age ranged from 25 to 39 (average age of 28.1, $SD = 3.7$) and 11 of them were male and two were female. All of them were native Dutch speakers. Ten of them had a normal hearing ability and three were hearing-impaired. In this experiment, hearing loss is constituted as a loss of at least 30 dB in the frequencies of 2 to 8 kHz in at least one ear. This frequency spectrum was chosen because of the aim of the experiment on consonants, of which the energy necessary to perceive them is between 2 and 8 kHz. A loss of 30 dB is considered as a mild but valid level of hearing loss, as mild hearing loss is defined as a loss of 26 to 40 dB (Clark, 1981). A normal hearing ability is defined in this experiment as having a maximum loss of 25 dB of any frequency in both ears, as a loss of less than 25 dB is not considered as a valid level of hearing loss and therefore normal hearing (Clark, 1981). The hearing ability of the participants was measured by pure-tone screenings with an Oscilla USB-330 audiometer. Air conduction thresholds were measured from 250 to 8 kHz and from these tests, audiograms were made. To minimize the effect of age-induced hearing loss, people over the age of 45 were not allowed to participate. People who reported having hearing loss since birth or early childhood and people with hearing aids or a cochlear implant were also excluded from participation. Most of the participants were students or alumni from the Radboud University Nijmegen. They were not paid for their participation in the experiment.

Materials

The materials used in this study consisted of VCV-stimuli. Apart from the alveolar /r/ because of pronunciation difficulties by the speaker of the recordings, all 24 Dutch consonants were used. To control for the effect of coarticulation, two vowel contexts were chosen, a high and a low vowel: iCi and aCa. Recordings of the stimuli were done in a sound-proof booth at Radboud University using a high-quality microphone. The frequency of the recordings was 44100 Hz. Multiple utterances of the stimuli were produced by the speaker and the most clear and best pronounced utterances were used for the experiment. The utterances were spoken clearly and at a normal speaking pace. The speaker was a female with little to no regional accent.

The stimuli were presented in a clean condition and in three conditions with different types of background noise. The types of noise used as maskers in this experiment are competing speaker (Comp), speech-shaped noise (SSN) and modulated speech-shaped noise (modSSN). The competing speaker noise consists of a man or a woman pronouncing Dutch words at a normal speaking pace. Speech-shaped noise is a stationary noise with a long-term average speech spectrum and no significant temporal modulations. Modulated speech-shaped noise is a non-stationary noise with a long-term average speech spectrum and temporal modulations derived from speech. So whereas SSN is a steady-state noise, modSSN and Comp have modulations in frequency and time, based on the spectrum of speech. To keep factors consistent among noise conditions, all three noise conditions have the same SNR, which is -10 dB. This SNR was determined with a pre-test done using a small group of participants, with the aim to find an SNR at which identification rates did not show ceiling performance but were also well above 50%.

The noise was added to the recordings using a PRAAT script, with 5 ms of silence before the noise plays over the utterance and 205 ms of silence before the beginning of the utterance. The noise was added by placing a random part of the noise file over the utterances. This procedure was done twice for every stimulus to create different versions of the masker noise with two different parts from the noise file and to produce more data points for the analysis. The stimuli of the clean condition were used twice. With 24 consonants, two vowel contexts, four noise type conditions and the two versions with different parts of the noise masker, 384 stimuli were used in each experiment.

Procedure

The experiment was conducted in a sound-proof booth. Before the consonant identification task started, the participants did a hearing test and they had to fill in a questionnaire about their work history, attendance of discotheques and concerts, and mp3-player usage in regards to their hearing ability.

For the experiment, the participants were instructed to listen to a stimulus with a VCV-nonword and possibly background noise, and answer what consonant they had heard. They gave that answer by pressing a key with a specific label on a keyboard. On those labels were Dutch letters that represented one of the 24 sounds the participants could choose from, as well as a word in which the consonant appeared, so the participants had a clear idea

of what the consonant sounds like. This keyboard can be seen in Figure 1. Before the real experiment started, they were presented with four test items. The participants performed the experiment while wearing headphones and stimuli were presented in both ears. The experiment was self-paced, but the participants could only listen to the stimulus once. The total amount of 384 stimuli was divided into 16 blocks of 24 stimuli, so that participants could take a short break every 24 stimuli if they needed to. A different noise type was presented every two blocks, but consonants and vowel contexts were randomised in those blocks. Every participant received the noise type blocks in a different order to control for possible order effects.

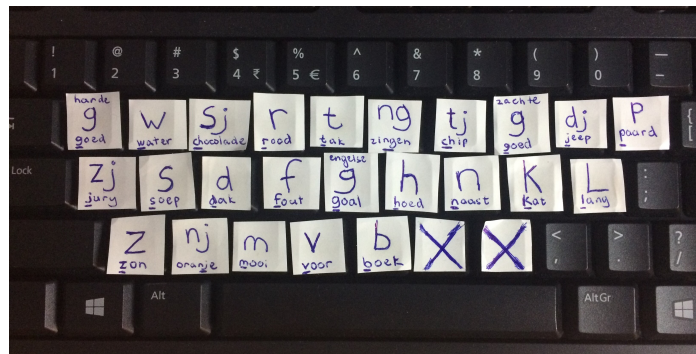


Figure 1: Keyboard with labels used in the experiment.

Results

Two Mixed ANOVAs were conducted. In the first analysis, the effect of having noise-induced hearing loss, different types of background noise and comparisons between these types, and the interaction effect between those two factors on consonant perception have been investigated by testing the main effect of hearing ability, the main effect of noise type and its contrasts, and the interaction of hearing ability and noise type. In the second analysis, the effect of the type of consonant in consonant perception and comparisons between groups of consonants have been investigated by testing for the main effect of consonant group and its contrasts. The groups of consonants in this experiment are divided into five groups: fricatives, plosives, nasals, affricates and approximants. By generalising the features of the sounds into groups, the effect of these sounds is easier to analyse. In Table 1, it is shown how all the 24 consonants used in the experiment are divided in these consonant groups. In both of the analyses, the dependent variable is the fraction of

correctly identified consonants. Multiple comparisons are compensated for with the Bonferroni correction.

Table 1. Division of consonants in consonant groups.

Categories	Consonants
Plosives	/p/ /t/ /b/ /d/ /g/ /k/
Fricatives	/f/ /v/ /r/ /s/ /z/ /ʃ/ /ʒ/ /x/ /ç/ /h/
Nasals	/n/ /m/ /ŋ/ /ɲ/
Affricates	/tʃ/ /tʃ/
Approximants	/v/ /l/

In the first ANOVA, the investigation of consonant perception between normal hearing people and people with noise-induced hearing loss was tested and no effect of hearing ability was found in consonant identification. Normal hearing people had better rates ($M = 0.751$, $SD = 0.027$) in consonant identification than hearing-impaired people ($M = 0.717$, $SD = 0.049$), but this effect was not significant ($F(1,11) = 684.9$, $p = 0.562$). These results show that having noise-induced hearing loss does not impact the performance in consonant identification.

For the research on the topic of different types of background noise, the effect of noise type in consonant identification has been found to be significant ($F(3,33) = 46.6$, $p < 0.001$). These results can be seen in Figure 2. Planned contrasts show that consonants are better identified in clean ($M = 0.900$, $SD = 0.021$) than in all of the other three conditions ($p \leq 0.001$). Furthermore, modulated speech-shaped noise ($M = 0.642$, $SD = 0.031$) proves to be a more effective masker than the competing speaker masker ($M = 0.739$, $SD = 0.043$, $p < 0.01$). Speech-shaped noise ($M = 0.655$, $SD = 0.028$) seems to be in between those two maskers in terms of the effectiveness of the masker, but those differences are not significant (difference with modulated speech-shaped noise: $p = 1.000$, difference with competing speaker: $p = 0.144$). In conclusion, the presence and type of background noise have an effect on the performance in consonant identification, with modulated speech-shaped noise being the most effective masker.

To investigate if consonant perception is different for normal hearing people and people with noise-induced hearing loss in a specific type of hearing loss, i.e., the effect the two factors have on each other, the interaction effect of the two factors was tested. This interaction effect between noise type and hearing ability was not significant ($F(3,33) = 0.428$, $p > 0.05$). So, the dif-

ferent types of noise and effect of hearing ability have no effect on each other.

In the second ANOVA, differences in consonant identification between consonant groups were found to be significant ($F(4, 44) = 34.9, p < 0.001$). This can be seen in Figure 3. There is a significant difference between the fricatives, plosives and affricatives on the one hand and the nasals and approximants on the other hand ($p < 0.001$). Those last two consonant groups (nasals: $M = 0.495$, approximants: $M = 0.586$) score much worse than the other three groups (fricatives: $M = 0.777$, plosives: $M = 0.847$, affricates: $M = 0.802$).

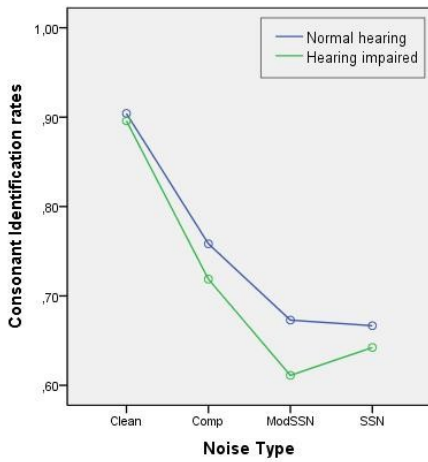


Figure 2: The fraction of correct consonant identification rates in clean and the 3 noise conditions: comp, modSSN and SSN, for normal hearing and hearing-impaired people.

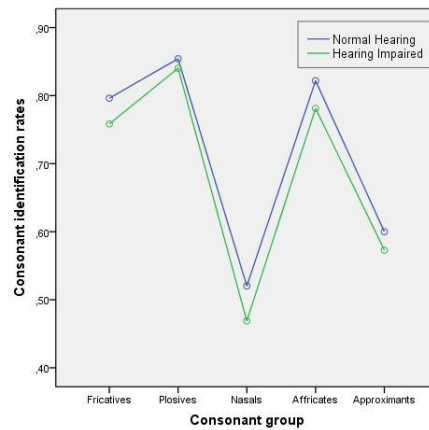


Figure 3: The fraction of correct consonant identification rates in the 5 consonant groups: fricatives, plosives, nasals, affricates and approximants, for normal hearing and hearing-impaired people.

Discussion

Results

Comparing our results to previous results reported in the literature, some interesting differences can be observed. For example, although only three participants were tested, the results show that people with noise-induced hearing loss do not significantly perform worse in consonant identification than people without noise-induced hearing loss, which is not in line with

studies like Sher & Owens (1974), Festen & Plomp (1990) and Scharenborg, Weber & Janse (2015), in which respectively high-tone frequency loss, general sensorineural loss and age-related hearing loss were investigated and the effect of hearing loss was found to be significant in consonant identification. A replication of the experiment performed in this article with many more participants may very well show results that noise-induced hearing loss has an appreciable effect.

Of the three hearing-impaired participants, the results of one participant were noticeably worse than the other two. That participant was also the only one of the three to report significant negative effects of his hearing ability in real life; he was also the only person of all the participants to report voices sounding muted or far away sometimes and he had the worse loss at 4 kHz (35 dB in left ear and 30 dB in right ear). This makes his hearing ability worse than the other two hearing-impaired participants. Moreover, from the questionnaires the participants filled in before the experiment became clear that this participant's hearing loss was most likely occupational, while the other two hearing-impaired participants' hearing loss was most likely recreational. This would make sense, because in an occupational setting the person would be exposed to noise much more frequently (almost every day, at work) than in a recreational setting, because people tend to visit concerts and discotheques less than once a week, as reported by the participants in the questionnaires.

As expected, consonant identification is worse in all three noise conditions compared to the condition without a masker. The effect of the temporal distribution in the masker, emphasized by the studies of Festen & Plomp (1990), Broersma & Scharenborg (2010) and Cooke (2006), is not evident in the results of the study in this article. For one, consonant identification rates in modulated speech-shaped noise are the worst of the three noise conditions, while this masker has temporal modulation in its frequency spectrum. Moreover, the consonant identification rates in modulated speech-shaped noise and the competing speaker condition differ significantly, while both have temporal modulations in their spectrum. So in this study, it seems that the long-term average spectrum of speech is a more important feature in a noise masker than the presence of temporal distribution, as the results also show that the two speech-shaped noise maskers are the most effective in masking consonant identification.

An interaction effect between the noise conditions and the hearing ability was not found. This is not remarkable, because it is also not shown in earlier studies. Moreover, this interaction effect would not be expected to appear,

because factors involved in the difference between types of background noise are not directly related to frequencies around 4 kHz (the frequency at which the hearing ability of people with noise-induced hearing loss is affected).

An interesting effect from the results can be seen in the analysis of the consonant groups. As is clearly evident from Figure 3, there is a division in performance in consonant identification between on the one hand fricatives, plosives and affricates, and on the other hand nasals and approximants. This is particularly interesting, because this division in consonant groups is fairly consistent with a division in sonorant and non-sonorant, i.e., obstruent, consonants. Affricates are after all a combination of a plosive and a fricative (both obstruents), with these sounds being articulated by a plosion followed by a fricative. An essential feature of sonorants is their resonance in the vocal tract, which is absent in obstruents. This resonance feature and the fact that it is not well transmitted in noise could be an explanation for why obstruents are well identified in this experiment. These results are still mostly inconsistent with previous research. Most research on this topic cites fricatives as the most difficult identified consonant group (Gelfand et al., 1986; Sher & Owens, 1974; Miller & Nicely, 1955; Garcia Lecumberri et al., 2008; Cooke & Scharenborg, 2008).

Methodological discussion points

An initial idea of an addition to the discussion of this article was that I would create a general audiogram with all Dutch consonants placed on their respective frequency and intensity with which they are typically spoken, as well as the mean hearing threshold of the participants of the experiment in order to investigate the quality of the perception of Dutch sounds by people with noise-induced hearing loss. Creating this audiogram seemed to be very difficult. After a lot of research on creating audiograms and similar experiments, I realised that there was very little information on frequencies of sounds, partially because this is speaker-dependent, but there were also very little approximations or means of those frequencies. Because of the lack of information, creating this kind of audiogram did not seem possible. When looking into the ways in which companies and articles made such an audiogram, it became apparent that none of those audiograms came with references or experiments on which the data was based. This might be because of the simplified image that audiograms of frequencies of sounds create. For instance, vowels are most often displayed at frequencies between 250 and 600 Hz. However, the first and second formants of those vowels have frequencies

up until 3 kHz and these formants contain information that is necessary for the correct identification of these vowels. The reason for most of these simplifications in audiograms and the lack of sources or references may be that these audiograms are often used for pamphlets and brochures about hearing loss for medical and informational purposes or for the hearing aids sale business. It is important for the people that will read these brochures that the information is understandable and because they most likely will not understand topics like phonological features, formants or phonetics in general. In order for these kinds of audiograms to be used in scientific articles, they should represent a more accurate portrayal of sounds and the frequencies and intensities at which they are perceived.

Although the experiment only included three participants, I tested a lot more participants that were willing to participate and assumed they might have some form of hearing loss. After those participants had performed the hearing test, it turned out that their hearing was not as bad as they expected and that they would fall into the ‘normal hearing’ category of the experiment. This means a lot of people assumed that they might be in the mild hearing loss category of this experiment (a loss of 26 - 40 dB), while in reality their hearing was better than they thought. What may play a part in too quickly assuming that one might have hearing loss, is the fact that problems in communication may be misidentified as problems caused by hearing loss. In this case, it is difficult for people to determine if hearing loss plays a part in causing these problems or if these difficulties are caused by something else (Kapteyn, 1994). Difficulties in understanding speech in background is one of the key symptoms of hearing loss and because this is quite well-known, people that suffer from difficulties in understanding speech in noise might immediately assume they have hearing loss, while this deficit can maybe be attributed to other causes. Issues in concentration and focus, and other social disorders can play a role in for example communicating and switching between conversations, which in the case of those participants could have been overlooked and mistaken for hearing loss.

As can be seen from the number of hearing-impaired participants in this experiment, finding participants who fulfilled my criteria of hearing impairment was very difficult. Among having done many other things, I reached out to multiple companies and establishments that deal with hearing loss and a lot of them have helped me and shared my call for participants on their social media pages. Although these messages reached a lot of people, few people fulfilled the criteria of hearing loss as defined for the purpose of this study or were too old to be able to participate. My inclusion criteria and the fact

that I was not able to compensate the participants with a reward were most likely the main reasons why I could not find enough participants, but a sense of pride in admitting to yourself or others that you are suffering from hearing loss and acting upon it by participating in these kinds of experiments might also have something to do with it. The pride and other emotional factors in having and admitting to having hearing loss is definitely something that can be elaborated upon in further research, for example by investigating in what way and why hearing loss holds people back from engaging in activities that concerns their hearing.

Summary and implications of the results

The results of this research show that different types of background noise have different effects on performance in consonant perception, with modulated speech-shaped noise as the most effective masker. Having noise-induced hearing loss does not show an effect on consonant identification and the interaction effect of hearing ability and different noise type is not present either. However, the type of consonants used in consonant perception in noise has an effect: fricatives, plosives and affricates are better perceived in noise than approximants and nasals.

These results can add to the body of research that has been done on the effect of hearing impairment on consonant identification in background noise. The results on the effect of noise-induced hearing loss shown in this experiment are actually new information for this topic. Unfortunately, not much is known about the effects of noise-induced hearing loss in this research topic, when in fact a lot of people suffer from it. Future research on noise-induced hearing loss could be done about how the listener's language affects their consonant perception or, as mentioned earlier, the effect noise-induced hearing loss has on engaging in activities regarding one's hearing.

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