CONCLUSIONS

The mean TMR_{60} (SRT) data obtained in the study showed no difference between performance in unmodulated and speech-modulated noise, indicating no benefit of dip-listening for this group of people with mild-to-moderate hearing losses.

The introduction of real speech as masking signal led to a significant increase in SRT, indicating an additional informational-masking effect. Adding target location uncertainty by randomly presenting the target from three different directions resulted in a significant increase in SRT of around 1 dB in the front direction.

The increase in SRT due to the introduction of speech masking and target location uncertainty does – together with subjective comments made by participants – indicate that the goal of increasing the ecological validity of the Dantale II test was reached.

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Confusion of Danish consonants in white noise

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Several classical studies have investigated how the perception of consonants is affected by interfering noise. The present study is aimed at developing a consonant confusion test, considering fifteen frequently used Danish consonants presented in initial position in combination with the vowels [æ], [i] and [u] and spoken by ten speakers. Consonant recognition was measured in the presence of a white-noise masker at a number of signal-to-noise ratios. The presented data were obtained in eight normal-hearing listeners. The results were analyzed in terms of recognition rates and formation of confusion groups. It was hypothesized that the confusion groups are similar to those found in English, but that consonants that are common in Danish would fall into specific groups. The results showed that there iss a large asymmetry in the confusions, and that the confusion groups are not as clear as in other languages. Additionally, this study introduces the "wheel of confusions" (WoC) which is a new graphical representation of consonant confusion data. The results will be used as reference data in on-going studies on consonant perception in listeners with hearing impairment and will address the individuality of consonant perception with and without hearing instruments.

INTRODUCTION

Understanding speech is one of the primary functions of human hearing. The processes underlying speech perception are sophisticated and comprise many stages that are challenging to investigate in isolation. Often, the recognition of whole sentences are considered, however, it may be of utmost importance to understand perception of smaller fragments of speech, e.g. on a phonemic level. In understanding naturally spoken sentences with meaningful context, many of the speech sounds do not necessarily have to be heard. It is therefore important for effortless speech understanding that the individual speech segments are perceived correctly, particularly for people with hearing impairment. Several studies on perception of spoken consonants (e.g., Miller and Nicely, 1955) have unveiled many interesting aspects, such as the categorization of consonants in voicing, place and manner of articulation. In recent years, studies of consonant recognition and confusions have gained popularity and have led to new insights on the relation between different spoken consonants, and new tools have been developed to analyse confusion data and the acoustic bases of consonants in relation to perception (e.g., Régnier and Allen, 2008). Recent data measured in listeners with hearing

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impairment have revealed that speech recognition rates, confusions and the influence of signal-to-noise ratio (SNR) are individual to the listeners and cannot be predicted based on their audiometric profile (Phatak *et al*., 2009). This means that a carefully designed consonant recognition and confusion test may have the potential of becoming a powerful tool for characterizing individual hearing impairment beyond the audiogram (Allen and Han, 2011; Jepsen *et al*., 2011)

In the present study, the idea was to develop a Danish version of a consonant recognition test, similar Miller and Nicely (1955), and to measure a normative data-set on normal-hearing listeners at a large range of SNRs. Many consonants are different across languages in terms of their pronunciation and frequency of occurrence in spoken language. The Danish test thus includes several other consonants and does not consider others compared to the established English test. The hypothesis is that the confusions, measured in Danish listeners, are grouped in a meaningful way as, for example observed in Miller and Nicely (1955) and Phatak *et al*. (2008).

This study additionally addresses the challenge of presenting the data in an appropriate and easily interpretable way. Earlier studies have typically used confusion matrices where rows and columns represent the played and heard consonants, respectively (Miller and Nicely, 1955; Allen, 2005). It was found that if the order of the consonants in the matrix was defined appropriately, confusion groups would appear as clusters in the matrix. The downside is that some trends may not appear in this representation, especially if the confusions are asymmetric, i.e. when two consonants are not confused similarly with each other. Another challenge is that a full confusion matrix needs to be presented for each SNR condition in the test. Phatak and Allen (2007) introduced a graphical representation, called confusion patterns, where the recognition and confusion were shown as a function of SNR. However, it was necessary to include a figure for each tested consonant of the test (e.g., 16 in Phatak and Allen, 2007; Phatak *et al*., 2008). In the present study, an alternative graphical representation is suggested, the "wheel of confusions" (WoC), where the data of all tested consonants and at all SNRs can be shown in a single representation. Here, the patterns of recognition and confusions can be compared easily across test conditions, e.g., for different types of noise or signals processed by different transmission lines such as telephones or hearing aids. The WoC representation may also serve as a tool for characterization of speech perception in hearing-impaired (HI) listeners where the WoC can be compared to the average NH listener, or even across ears within the HI listener.

EXPERIMENTAL METHODS

The task of the listeners was to identify the perceived consonant in a consonant-vowel (CV) stimulus, either in quiet or in conditions of stationary white noise at different SNRs. The speech material was recorded at the Centre for Applied Hearing Research at the Technical University of Denmark. In the current study, the recording from five male and five female talkers were used. CVCV utterances were recorded, and the speech stimuli used here were the initial CVs extracted from these recordings. Fifteen of the most frequent Danish consonants were chosen and are listed in Table 1. The CVs consisted of one of the consonants in combination with one of 3 vowels (/a/, /i/ or /u/). In the test, the listeners were presented with one CV on one ear via headphone, and were asked to indicate the perceived consonant on of fifteen buttons (closed set test) on a graphical user interface on a computer screen. The next CV was played after a response. In the conditions with white noise, the CV stimulus was embedded in and preceded by 400 ms of noise. The level of the CVs was defined by a volume unit measure (see e.g., Phatak *et al*. 2007), and the level of the noise was defined as its *rms* level. The tested SNRs were -15, -12, -6, 0, 6 and 12 dB. The speech level was held constant at 65 dB SPL.

Phoneme	/p/	/t/	/k/	/b/	/d/	/g/	/f/	/s/	/v/
IPA phone	[pʰ]	[tˢ]	[kʰ]	[b̥]	[d̥]	[g̊]	[f]	[s]	[ʋ]
Symbol	△	◇	▽	▲	◆	▼	✳	○	▶
Phoneme	/m/	/n/	/l/	/h/	/j/	/S/	/a/	/i/	/u/
IPA phone	[m]	[n]	[l]	[h]	[j]	[ʃ]	[æ]	[i]	[u]
Symbol	★	☆	□	▷	■	●			

Table 1: Phoneme and IPA representation of the fifteen tested consonants and three vowel. The symbols are used to indicate responses in Fig. 2.

RESULTS

Figure 1 shows the confusion matrix of the data obtained in the eight NH listeners at an SNR of 0 dB. The diagonal represents the correctly recognized consonants. At this SNR, the consonants are usually recognized correctly, but some confusions appear. Confusion clusters can be identified, which are asymmetrical, e.g., /S/ is sometimes confused with /s/, but /s/ is rarely confused with /S/. The most clear clusters are the groups /b, d, g/, /k, p/ and /m, n/. /m, n, j, l/ are confused with /v/ , /b/ with /f/, /p/ with /h/, and /h/ with /p/. These results only represent the data at this particular SNR.

Response (columns) / stimulus (rows)

	b	d	g	k	p	t	m	n	v	s	Sj	f	h	j	l	sum
b	88	33	11	9	20	2	0	2	26	1	0	44	15	3	7	261
d	29	156	29	4	8	5	0	5	3	1	1	14	2	5	7	269
g	18	34	103	10	21	0	1	9	12	0	1	4	13	26	3	255
k	7	12	14	115	62	9	0	2	0	1	0	20	34	4	3	283
p	10	9	8	47	116	6	0	2	3	1	2	22	50	2	0	278
t	0	4	0	3	2	230	0	0	0	13	2	10	0	0	0	264
m	2	1	1	1	2	0	85	75	64	0	0	1	3	11	26	272
n	1	1	2	1	3	0	34	122	38	0	0	0	4	14	48	268
v	5	3	2	1	2	0	1	6	205	0	0	0	5	17	27	274
s	0	1	1	0	0	34	0	0	0	248	13	4	0	1	0	302
Sj	0	0	1	0	0	33	0	0	0	48	192	2	0	1	0	277
f	32	17	7	19	25	3	0	1	9	3	2	128	14	0	1	261
h	20	20	14	27	50	4	1	4	11	2	0	30	82	6	1	272
j	1	2	5	2	3	0	3	17	73	0	0	0	2	136	27	271
l	1	5	2	0	0	0	5	21	77	0	0	1	0	20	138	270

Fig. 1: Consonant confusion matrix showing the data obtained in eight normal-hearing listeners at an SNR of 0 dB.

To indicate how the confusions as a function of SNR, the confusions patterns (Phatak, 2007) of the played consonants /b, d, g, p, k, t/ are shown in Fig. 2 as examples. The symbols representing the different consonants can be found in Table 1. In the panel showing the results of /b/ it can be observed that the recognition rate increases with increasing SNR. At the two lowest SNRs (-15 and -12 dB), many of the consonants are represented in the responses to /b/. For /b/ at SNRs of -6, 0 and 6 dB, three clear confusions can be observed, /f, d, v/. Here, they are called the "dominant confusions". Similar trends, with different confusions, can be seen in the other five examples. For /d/ the dominant confusions are /b, g/. For /g/ there is one dominant confusion /j/, for /k/ they are /p, h/, for /p/ they are /k, h/ and for /t/ the dominant confusion is /k/.

In the WoC (Fig. 4), each of the fifteen played consonants is represented in one segment (or spoke) of the wheel. Figure 3 is an example of how /b/ is represented in the WoC. The bold-faced letter /b/ indicates the stimulus consonant, and the two other consonants represent the 2 most dominant confusions, here /f/ and /v/. These were derived from the confusion patterns of Fig. 2. The SNR conditions are represented as the distance from the wheel's centre, ranging from the quiet condition (Q) to conditions of varying SNRs. The angles (heights) of bars in the darkest color indicate the recognition rate from 0 up to 100%. It can be observed that in condition Q this rate is 100% since the bar fills the whole range of the spoke and the rate drops with decreasing SNRs.

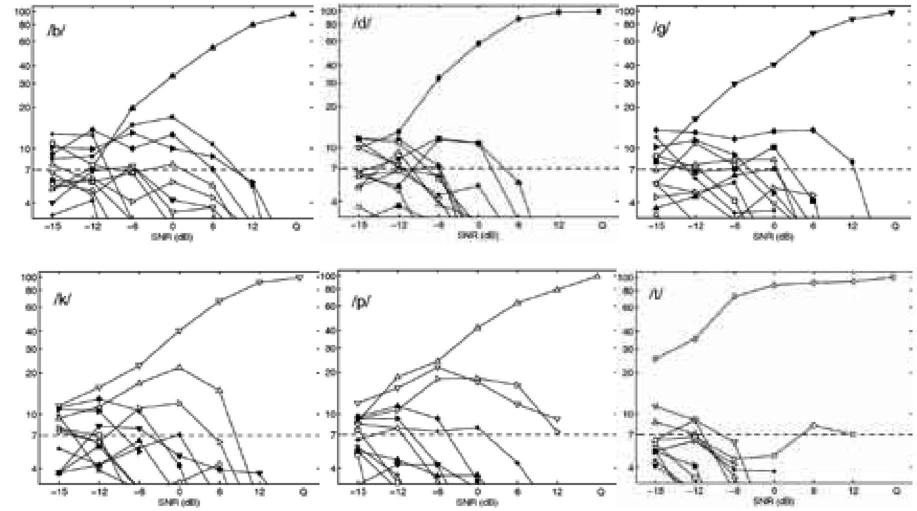

Fig. 2: Confusion patterns of six exmplary consonants. One panel per consonant is shown. The horizontal dashed line indicates the chance level. The symbols represent the different consonant responses. The table 1 for the definition of the symbols.

The confusion rates of the two dominant confusions are shown as brighter-colored bars stacked on top of the existing bars. It can be seen that these confusions start to appear at SNRs of 6,0 and -6 dB. At the two lowest SNRs (-12 and -15 dB), the recognition rates and the confusions are similar and close to chance level. More confusions could be represented in the WoC but here only the two most dominant ones are shown.

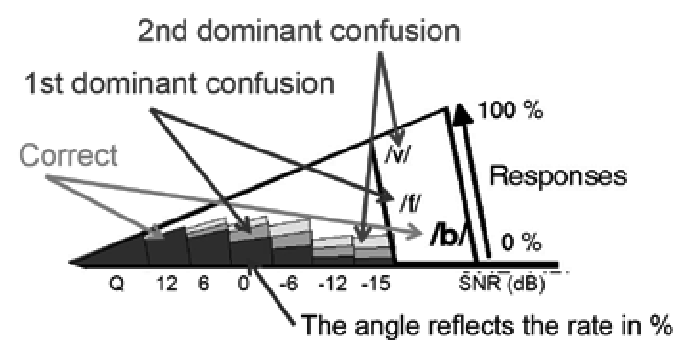

Fig. 3: Example of one segment of the wheel of confusions. The darkest color reflects the recognition rate, and brighter colors reflect the 1st and 2nd order confusions.

Figure 4 shows the full WoC of the data obtained with the eight NH listeners. The consonants are organized according to their phonetic category: “plosives”, “nasals”, “fricatives” and “approximants”. From this graphical representation it can be observed that consonants /d, t, s, Sj, v/ have relatively dark-colored spokes, indicating a large recognition rate and thus robustness of the consonants to noise. /m/ and /h/ are examples where low recognition scores were observed. From the confusion rates (brighter-colored bars) it appears that some consonants are more often confused, e.g. /m, s, j, l/ whereas /b, d, g, t, f, h/ are rarely confused by these listeners, since the confusion rate of the dominant confusions are relatively low.

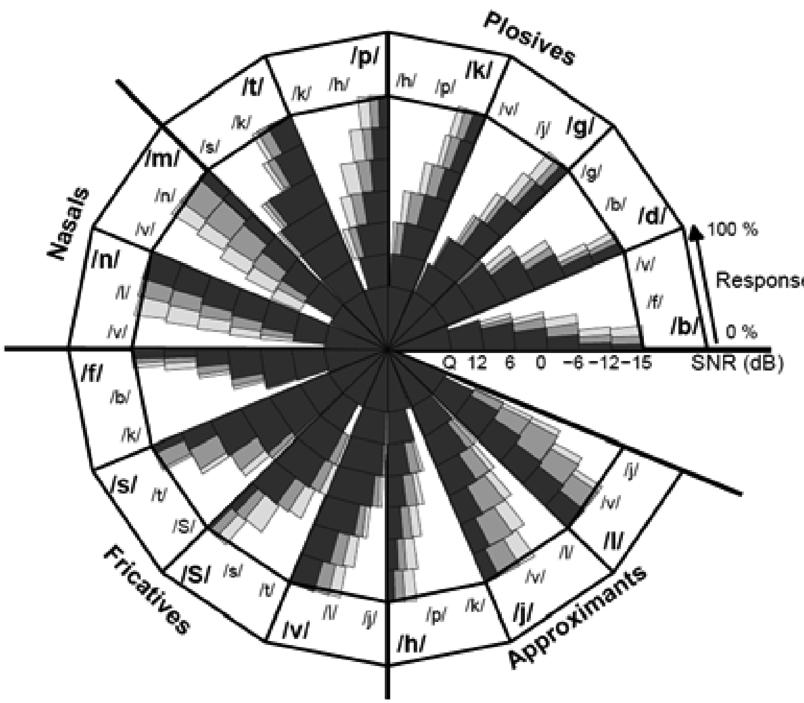

Fig. 4: Wheel of confusion (WoC). See Fig. 1 for detailed description. The consonants are ordered due to their phonetic category (plosives, nasals, fricatives and approximants).

DISCUSSION AND SUMMARY

The results of this study show that the confusions among these fifteen Danish consonants are not comparable to the observed confusions in, e.g., English (Miller and Nicely, 1955, Phatak *et al*. 2008). The consonants are phonetically different in the various languages, and the frequency of their occurrence in the individual languages is different. It is therefore crucial that listeners are tested with speech stimuli of their native language. In Miller and Nicely (1955) and subsequent studies, the confusion groups have been associated with the concepts of voicing, manner and place of articulation. In the data of this study, the observed confusions do not relate as strongly to these articulatory features.

It is interesting that the present data rarely show symmetry in the confusions. Such symmetry was only observed for the /b, d/, /d, g/ and /k, p/ confusions. The characteristics of the noise may play an important role here. Phatak *et al*. (2008) measured English confusions were measured in white noise and found a weaker symmetry compared to the data of Phatak and Allen (2007) where the confusions were obtained with a speech-shaped-noise masker. The present study revealed that the confusions of Danish consonant were more difficult to categorize compared to studies of English confusions

The wheel of confusions suggested in this study is a new graphical representation of consonant recognition and confusion data. One figure can represent response rates for an arbitrary number of tested consonants and various SNR conditions. The visual presentation of the data in the WoC might allow for an easier comparison of two alternative processing strategies. Future studies and applications could use the WoC representation to analyze, e.g., the influence of a transmission line, such as a mobile telephone, on speech transmission. In the clinical setting it may be possible to illustrate to the clinician or the patient how a hearing-instrument affects the recognition of speech on a consonant level. This may be a tool for fine tuning of the hearing-instrument processing or as a representation that allow the patient/clinician choose between hearing aids or a processing strategies based on a data-based measure complementary to their subjective impression.

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Assessment of auditory processing in children demonstrating symptoms of (Central) Auditory processing disorder (C)APD

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(Central) auditory processing describes functions such as sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition (e.g., temporal gap detection), temporal ordering, and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals. Poor performance in one or more of these abilities without signs of degraded abilities of higher order cognitive/communicative and/or language-related functions might be a symptom for (Central) Auditory processing disorder, (C)APD. For school-aged children, (C)APD can manifest itself in difficulties in learning, speech, language, social, and related functions. However, depending on individual combinations of "bottom-up" and "top-down" abilities, the same aspect of auditory processing deficit may influence different children in different ways, which makes standardised ways of a diagnostic approach difficult to establish. During the last two years, a multidisciplinary team at Uppsala University Hospital has worked on diagnosis and management of children demonstrating symptoms of (C)APD. Results of measurements of auditory processing of 50 children as well as approaches to manage their problems are presented and discussed.

INTRODUCTION

Auditory Processing Disorder (APD) is a diagnose to be considered on the basis of difficulty in identifying or discriminating sounds despite normal hearing thresholds. Difficulty in understanding speech in noise is the most common manifestation, but other symptoms such as problems remembering orally given instructions, localising sounds or abnormal sensitivity for loud sounds may also occur (ASHA, 2005). Research on diagnosing APD has been done in several years, but there are still discussions of the feasibility of some test procedures, and of associations of APD with learning and language problems (Moore, 2006). Even though there have been several suggestions on how to develop relevant, multiprofessional diagnostic approaches (Witton, 2010), such diagnostic approaches have been hampered by considerations on co-morbidity of APD with other problems such as language and/or

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