Speech Recognition in Noise in 5-Year-Old Normal-Hearing Children

La reconnaissance de la parole dans le bruit par des enfants de cinq ans qui ont une acuité auditive normale

KEY WORDS
SPEECH RECOGNITION
NOISE
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Abstract

Objective: The objective of this study was to investigate if Hagerman's 3-word-utterances in monaural or binaural noise are appropriate for testing 5-year-old children.

Design: This test is a modification of Hagerman's 5-word-sentences, where the first two words are omitted in order to make it easier for children. The influence of three factors were evaluated; type of noise (slightly or fully modulated), noise presentation (monaural or binaural), and gender (male or female).

Study sample: Twenty normal-hearing 5-year-old children.

Results: The 5-year-old children could not take advantage of the short valleys in the modulated noise in the 3-word-utterances to the same extent as adults could in the original 5-word-sentences. A significant improvement was obtained with binaural noise compared to monaural noise (binaural masking level difference, BMLD) for both slightly and fully modulated noise. Boys showed significantly better results than girls.

Conclusions: The children were able to complete this test without problems. The results may be used as preliminary reference material for 5-year-old children.

Abrégé

Objectif : Explorer si les énoncés de trois mots de Hagerman dans des situations d'écoute monaurale ou binaurale dans le bruit sont appropriés pour évaluer des enfants de cinq ans.

Conception: Ce test est une modification de celui de phrases à cinq mots de Hagerman où les deux premiers mots sont enlevés pour que ce soit plus facile pour les enfants. L'influence de trois facteurs a été évaluée : le type de bruit (légèrement ou entièrement modulé), la présentation du bruit (monaurale ou binaurale) et sexe (gars ou fille).

Échantillon de l'étude : Vingt enfants de cinq ans ayant une acuité auditive normale.

Résultats : Les enfants de cinq ans n'ont pas pu bénéficier des courts intervalles de silence dans le bruit modulé des énoncés de trois mots autant que les adultes ont pu le faire avec les énoncés originaux de cinq mots. Les résultats montrent une amélioration significative des performances avec les bruits binauraux comparé aux bruits monauraux (différence des seuils masqués en binaural, DNMB) pour les deux types de bruit. Les garçons ont obtenu de meilleurs résultats que les filles.

Conclusions : Les enfants ont réussi ce test sans problème. Les résultats peuvent être utilisés à titre de référence préliminaire pour les enfants de cinq ans.

Abbreviations:

BMLD, binaural masking level difference
FUM, fully modulated
FUMB, fully modulated, binaural
SM, slightly modulated
SMB, slightly modulated, binaural
S/N, signal-to-noise ratio

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Introduction

The often noisy environment in preschools (McAllister, Granqvist, Sjölander, & Sundberg, 2009; Sjödin, Kjellberg, Knutsson, Landström, & Lindberg, 2012) can make it difficult for anyone to communicate. For a child, even a minimal degree of sensorineural hearing loss degrades the ability to recognize speech in noise (Crandell, 1993). It is therefore important to have a test for children's – and especially for hearing impaired children's – ability to communicate in noise. To date, a speech-in-noise test for children has been lacking in Sweden. Such a test may be useful for functional and differential diagnostics of children with hearing impairment. Furthermore, some children with learning problems experience speech-sound perception deficiencies that are wore in background noise (Cunningham, Nicol, Zecker, Bradlow, & Kraus, 2001). In Sweden, Hagerman's 5-word- sentences in noise is a test widely used for adults. However, for young children five words at a time can be too many for their short-term memory. Gathercole, Hitch, Service, and Martin (1997) showed that five-year-old children could not repeat more than four digits at a time. Therefore, a modified version of the Hagerman's test material using only 3-word-utterances was prepared and evaluated.

When listening monaurally to speech in noise, it will be easier to recognize speech if the same noise is also presented simultaneously to the opposite ear. This is one example of the so-called binaural masking level difference (BMLD), although the basic form of BMLD makes use of dichotic signals with 180 degrees phase difference of the signals and identical noise in the two ears (Johansson & Arlinger, 2002). Similar results are obtained with signals other than speech; e.g., pure tones. By adding an identical and in-phase noise contralaterally to the 3-word-utterances, we added a BMLD test to the study, although this part of the test was only a secondary goal. It may be valuable as a diagnostic test of children with perceptual problems (e.g. Putter-Katz, Feldman, & Hildesheimer, 2011; Sweetow & Reddell, 1978). However, some researchers have found no relationship between BMLD results and language problems in children (Breier, Fletcher, Foorman, Klaas, & Gray, 2003; Roush & Tait, 1984). We found very few articles on this issue and none using speech as the stimulus signal in the BMLD measurements.

Objective

The purpose of this study was to investigate if Hagerman's lists of 3-word-utterances in monaural or binaural noise are suitable for testing 5-year-old children.

Methods

Speech and noise material

Hagerman's sentence lists consist of 10 lists, each with ten 5-word-sentences (Hagerman, 1982). All lists have the same content of recorded words, but in different order. This gives a high probability that the lists are equally difficult for any individual. Only one original list of sentences was recorded. Then each word was cut out digitally and new lists with new sentences were put together. "Peter bought six new pencils" is an example of an original sentence. All sentences are constructed in a similar way. In another list one might find the sentence "Anna bought five new balls". Test-retest reliability for normal-hearing adults, using two lists for a threshold measurement is 0.4 dB in the slightly modulated noise (Hagerman & Kinnefors, 1995) and 0.6 dB in the fully modulated noise conditions (Hagerman, 1997). Speech-in-noise tests of this type are now available in many languages (Zokoll et al., 2013).

To create 3-word-utterances, the recordings of Hagerman´s Swedish 5-word-sentences in noise were used with the original versions of the various words stored digitally in the computer with a sampling rate of 30 kHz (Hagerman, 1982). The first two words in each sentence ("name + verb") were omitted, resulting in utterances like "six new pencils"; i.e. "numeral + adjective + noun". There were 12 lists, each with ten 3-word-utterances. All lists had exactly the same recordings of the 30 words. The same noise signals as those described below for the 5-word-sentences were used for the 3-word-utterances. There were two versions of the noise, the original, "slightly" modulated (SM) and a modified version, which is "fully" modulated (FUM). Both had a long-term average spectrum identical to that of the speech read by a female voice and were produced from, and for, the 5-word-sentences. The modulator was a noise with most of its energy between 1 and 5 Hz , and with a spectrum similar to the modulation spectrum of normal speech (Hagerman, 1982). The SM noise was modulated to a degree of 10%. The FUM noise was modulated to a degree of 100%; i.e., with the modulator level varying through the full range of the digital-analogue converter. The SM noise was identical for all sentence lists used (Hagerman, 1982). However, the FUM noise was different for each sentence list, since it had been cut into pieces and put together again in order to get the same noise segment behind identical words in the different lists (Hagerman, 1997). The noise was presented either monaurally in the same (right) ear as the speech, or binaurally in both ears simultaneously with identical phase in both ears.

The speech level was defined as the equivalent unweighted long-term sound pressure level of the speech signal without pauses between the sentences. The noise level was defined accordingly. The calibration was made using a Brüel & Kjær Artificial Ear, Type 4153.

Subjects

Twenty-four children from two different preschools participated in the study. Tympanometry was conducted after the speech tests were administered. The inclusion region was +/- 100 daPa. After testing, speech test results for four children were omitted due to unsatisfactory tympanometry results. Therefore, results are based on 13 boys and 7 girls (mean=5.7, SD= 0.3 years). No audiograms were collected, but all were considered to have normal hearing based on parents' knowledge about earlier hearing tests, mostly from the general Swedish check-up, including hearing tests, at 4 years of age. All children were considered to have typical development, since no parents were aware of any learning difficulties or other related difficulties. All children had Swedish as their native language and no one had a severe cold at the time of the test. Hogan and Moore found that among children with a history of otitis media effusions those with an effusion prevalence within the fourth quartile had significantly worse BMLD results compared to the rest of the group, as measured when the ears were normal (Hogan & Moore, 2003). However, the children in our test group had no such problems, according to the parents.

Equipment

The measurements were performed in quiet rooms in the two preschools. Speech and noise signals were presented from a signal processor (Tucker-Davis Technologies, System 3) via headphones (Sennheiser, HDA 200). A personal computer containing our software controlled the signal processor and the test routine. All computer and the Tucker-Davis equipment software was written in our laboratory.

Procedure

Ear canals and eardrums were checked with an otoscope. Speech was always presented to the right ear. The noise was presented either to the right ear or binaurally, with the level fixed at 65 dB SPL (calibrated on an artificial ear B&K 4153). Each subject listened to 10 lists, including two training lists. The first utterance of the first training list had a signal-to-noise ratio (S/N) of +10 dB. As long as 2 or 3 correct words were obtained, S, the speech level, was decreased 5 dB after each utterance. After the first time that only 1 or 0 correct words were obtained and onwards, the speech level was changed after each utterance according to the adaptive scheme shown in Table 1. This scheme was then continuously followed between and within consecutive lists. The method aims to achieve a threshold of 67% correct answers, instead of 40 % as in the original test, to keep the children motivated.

After each utterance the noise was stopped and an oral response was awaited. When the number of correct responses had been recorded, the next utterance was presented. The mean value of the S/N settings, in dB, chosen after each of the ten utterances, was presented as the threshold value of the list. Five test lists were presented with the SM noise and five with the FUM noise. The children were divided into two groups. Group 1 (n=12) started with a training list and four test lists with the SM noise; two lists (i.e. test-retest) with monaural noise and then two lists with binaural noise (the last two called SMB). They then listened to one training list and four test lists with the FUM noise, two lists with monaural noise, and then two lists with binaural noise (the last two called FUMB). Group 2 (n=8) were tested in the same way, but with the two types of noise in reverse order, to balance learning effects for the two types of noise. However, due to the drop-out of four subjects with unsatisfactory tympanometry, the balancing of the learning effects between the two noise types was slightly reduced.

Table 1. Change of speech level (dB), after an utterance, based on number of correctly repeated words. This scheme pertains to the SM noise. When the FUM noise is used the size of the changes are doubled. This scheme was used throughout the study after the first time less than 2 correct responses out of 3 were obtained.

Number of correct responses	0	1	2	3
Speech level change, dB	+2	+1	0	-1

The duration of the whole test procedure was about one hour, including an intermission of 15 to 20 minutes.

Results

Raw data are shown in Table 2. To obtain good reliability in a clinical test routine, we suggest that the threshold should be measured with one training list and two test lists. Therefore, mean thresholds were also calculated for the two-test and retest lists that had equal presentation modes. This resulted in four mean values per subject, one for the SM noise (with monaural noise), one for the SMB noise (with binaural noise) one for the FUM noise (with monaural noise), and one for the FUMB noise (with binaural noise).

Table 2. Individual and mean threshold values in dB for the first and second test list in each presentation mode. Subjects with numbers above 200 started with the four thresholds in the FUM noise. SM=slightly modulated, SMB=slightly modulated, binaural, FUM=fully modulated, FUMB=fully modulated, binaural. The last three rows show the standard deviations of the individual test and retest means.

Subject	Gender	SM1	SM2	SMB1	SMB2	FUM1	FUM2	FUMB1	FUMB2
104	girl	-3.0	-4.6	-7.0	-7.2	-3.6	-2.6	-4.4	-4.4
105	girl	-2.6	-3.2	-4.0	-6.4	1.2	-2.2	-2.2	-9.2
204	girl	-3.2	-1.6	-4.4	-4.9	-3.6	-5.8	-5.2	-7.4
101	girl	-3.6	-3.0	-5.1	-6.9	-2.4	-4.4	-7.2	-9.8
102	girl	-3.2	-3.1	-4.5	-6.9	-1.2	-5.2	-7.0	-6.6
103	girl	4.6	0.9	-1.7	-3.5	0.8	-1.8	-5.4	-6.2
201	girl	0.2	-3.1	-6.0	-4.8	-0.3	-0.6	-1.2	-4.0
154	boy	0.2	-2.3	-6.0	-4.9	-0.8	-0.8	-5.0	-4.6
155	boy	-4.5	-4.5	-7.4	-7.9	-4.6	-6.8	-6.8	-9.6
156	boy	-4.0	-4.2	-6.8	-8.1	-4.2	-5.4	-9.4	-8.8
255	boy	-3.1	-4.4	-3.8	-6.6	-4.4	-1.0	-5.6	-6.6
256	boy	-3.1	-2.8	-3.6	-5.2	-3.6	-3.3	-5.4	-7.4
257	boy	-5.5	-4.9	-6.6	-6.9	-2.8	-3.6	-9.0	-9.4
151	boy	-3.2	-3.8	-5.6	-5.6	-4.2	-4.0	-6.8	-7.4
152	boy	-3.7	-5.2	-6.8	-8.3	-5.4	-6.2	-10.4	-10.8
153	boy	-3.3	-5.0	-6.3	-6.4	-4.8	-6.0	-7.0	-9.2
251	boy	-4.0	-4.1	-6.6	-6.6	-2.4	-2.6	-6.0	-5.0
252	boy	-5.4	-5.9	-7.8	-8.6	-2.2	-3.2	-8.8	-9.0
253	boy	-5.6	-5.6	-7.2	-7.1	-2.8	-2.4	-6.8	-8.2

Table 2. Continued

Subject	Gender	SM1	SM2	SMB1	SMB2	FUM1	FUM2	FUMB1	FUMB2
157	boy	-2.9	-3.5	-5.4	-7.0	-3.4	-4.0	-5.4	-9.2
mean	girls	-1.5	-2.5	-4.7	-5.8	-1.3	-3.2	-4.7	-6.8
mean	boys	-3.7	-4.3	-6.1	-6.9	-3.5	-3.8	-7.1	-8.1
mean	girls+boys	-2.9	-3.7	-5.6	-6.5	-2.7	-3.6	-6.3	-7.6
mean	girls	-2.0		-5.2		-2.3		-5.7	
mean	boys	-4.0		-6.5		-3.7		-7.6	
mean	girls+boys	-3.3		-6.1		-3.2		-6.9	
SD	girls	2.24		1.39		1.75		1.86	
SD	boys	1.22		1.11		1.47		1.64	
SD	girls+boys	1.86		1.33		1.67		1.91	

Analysis of variance was carried out to check if there were significant differences, with the independent variable gender as a between-subject factor, and with type of noise (SM, FUM), noise presentation (monaural, binaural), and test-retest as within subject factors.

The following main factors were found to significantly influence results: test-retest ($p<0.00001$), monaural-binaural noise ($p<0.00001$), and gender ($p=0.011$). The following interactions were significant: test-retest/gender ($p=0.018$), and SM-FUM/monaural-binaural ($p=0.043$).

The significant mean test-retest difference, i.e., between consecutive lists with equal presentation mode, was 1 dB (0.7 dB for the boys and 1.4 dB for the girls). These differences represent the learning effect. The overall significant gender difference was 1.65 dB, with boys having better thresholds. The significant difference between all thresholds with monaural noise and those with binaural noise was 3.3 dB, with binaural noise giving better thresholds. This significance difference also held for the two types of noises separately. There was no significant difference between the overall mean thresholds with SM noise and with FUM noise. However, there was a significant difference of 0.8 dB between the results with SMB noise and FUMB noise. Table 3 shows more detailed results of test-retest differences. The standard deviation of the test-retest differences divided with $\sqrt{2}$ represents the repeatability; i.e., the standard deviation expected for many repeated measurements.

The mean results for boys and girls are shown in Figure 1. The results for the boys were better than those of the girls for each type of noise and noise presentation.

Discussion

The measurements were performed in ordinary rooms in the preschools and not in sound proof booths. However, the earphones HDA200 have good attenuation of sounds from the outside, since they are circumaural and reconstructed ear muffs. Furthermore, the noise in the test was 65 dB SPL. The audiologist who performed the measurements clearly stated that the environmental noise was marginal and could not influence the measurement results. It was not measured by a sound level meter.

Four children were excluded after tympanometry, although a slight conductive loss for a child would probably not have influenced the group result. Speech-in-noise tests are not very sensitive to the absolute level of the signals and the signal-to-noise ratio is the crucial variable.

The most important part of this experiment was to gather monaural data on children for speech in the SM noise. The BMLD measurements are regarded as an option, and were included since they were easy to incorporate. However, we do not yet know whether it is worthwhile to use these measurements. We recommend that two lists be used to obtain threshold after the training list, to enhance

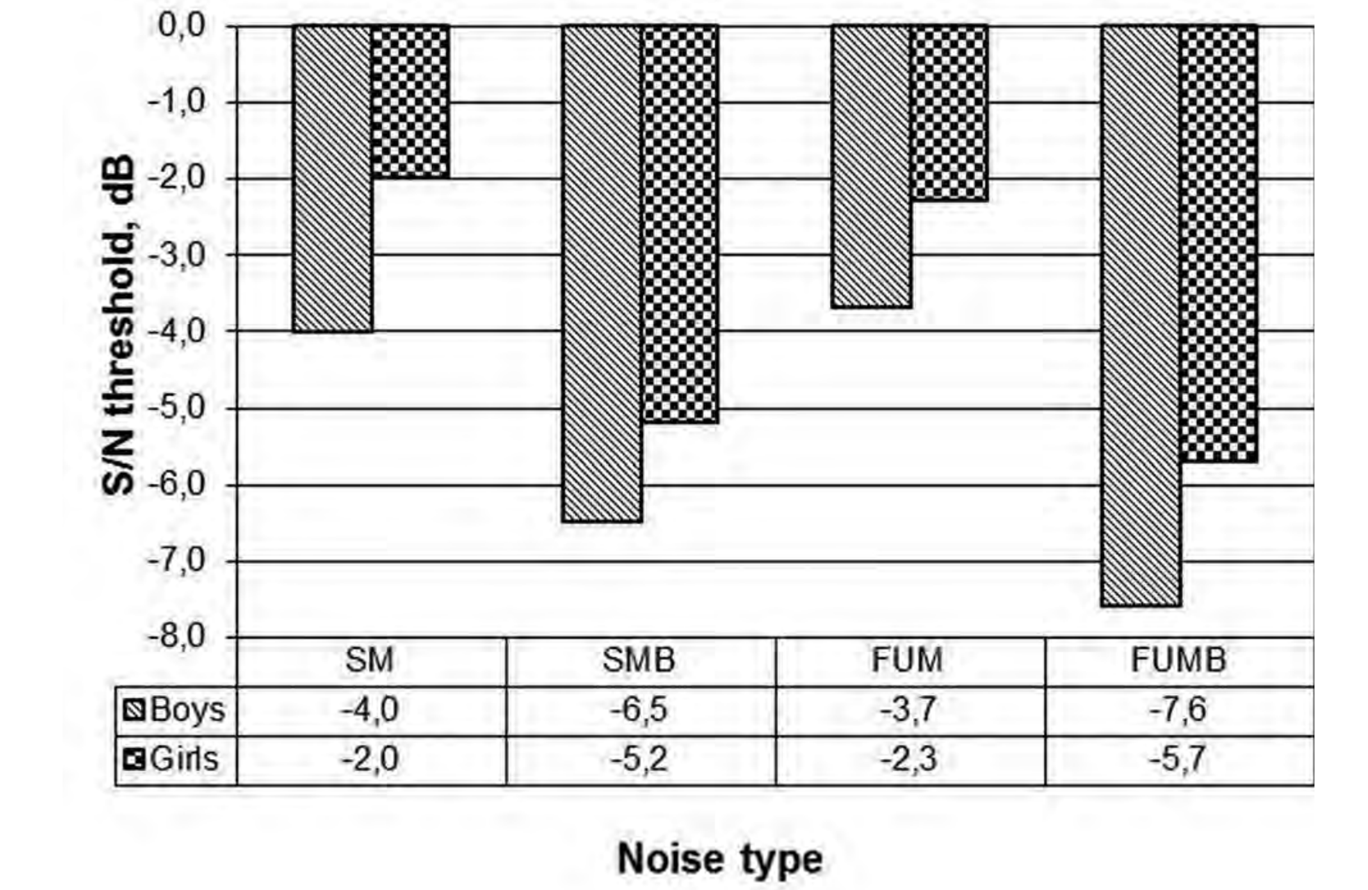

Figure 1. S/N threshold means for boys (n=13, left bars) and girls (n=7, right bars) separately for the different types and presentation modes of the noise. SM=slightly modulated, SMB=slightly modulated, binaural, FUM=fully modulated, FUMB=fully modulated, binaural.

Table 3. Means and standard deviations of the differences between test and retest results for the two types of noise and for monaural and binaural noise presentations. SM=slightly modulated, SMB=slightly modulated, binaural, FUM=fully modulated, FUMB=fully modulated, binaural.

Noise type		SM	SMB	FUM	FUMB
	Gender				
mean	girls	1.0	1.1	1.9	2.1
	boys	0.6	0.7	0.3	1.0
	girls+boys	0.8	0.9	0.9	1.4
SD	girls	2.0	1.3	1.7	2.5
	boys	0.9	1.0	1.3	1.4
	girls+boys	1.3	1.1	1.6	1.9

the reliability, corresponding to the recommendation for the 5-word lists for adults. Therefore we presented the mean values of results for two lists. However, due to time limits, only one list was used in our experiment, and one for the retest procedure. It is well known that test-retest uncertainty is increased by a factor of √2 if half lists are used (Hagerman, 1976). For example, the standard deviation of the test-retest difference would have been 1.3/√2=0.9 for the whole group in the SM noise (Table 3, last row), if two lists per threshold were used. To obtain repeatability of thresholds measured using two lists, i.e., the standard deviation of many repeated thresholds it is necessary to divide by √2 again, which yields a value of 0.65. However, the learning effect is not included.

In this study, one girl achieved poor results, especially on the first half of the test (Table 2, No. 103). The reason for the poor performance is unknown, but a conductive loss can probably be excluded, since her tympanometry result was normal. The influence of her results makes the group results for the girls less reliable than those of the boys. However, even when these results were omitted, boys scored significantly better than the girls.

The results were compared to results for normal-hearing adults (Köbler, 2007). However, to compare results, differences in measurement methods had to be compensated for due to different definitions of the threshold. The method for the 3-word-utterances defines the threshold as 67% correct words, while the original 5-word-sentences for adults defines the threshold as 40% correct words. The psychometric function in Figure 4 in Hagerman (1982) shows that a 1.32 dB higher S/N-ratio is needed to acheive 66.7 % correct words compared to 40 % for normal-hearing adults with the 5-word-sentences. Table 4 shows the mean thresholds of the children, with the compensated results of Köbler (2007) within brackets. The BMLD values can be used directly for comparison purposes, since they express differences.

According to Boothroyd (1997) phoneme recognition of children does not reach the asymptotic value of adults until the age of about 12 years. In our experiment the 5-year-old children needed more than 2 dB better S/N to reach the same recognition level as that of adults in the monaural SM noise. Blandy and Lutman (2005) measured speech recognition of 7-year-old children for sentences in unmodulated noise. They found 3 dB worse thresholds in noise compared to young adults, a difference which is similar to our results. Hall, Grose, Buss, and Dev (2002) obtained almost 5 dB worse spondee thresholds in continuous noise for 6-year-old children compared to adults. In fully modulated noise the difference between children and adults is further enhanced. The release of masking in gated noise was 2 dB for the children and 4 dB for the adults in their study. The adults in Köbler's study, had as much as 10 dB better results in the modulated noise (FUM) compared to the SM noise (Köbler, 2007). The children in our study could obviously not take advantage of the valleys in the noise fluctuations since there was no significant difference between their results in SM noise and in FUM noise. Stuart (2005) found differences between speech recognition results in interrupted and continuous noise in children 6 to 15 years old. This difference increased with increasing age.

The advantage of binaural instead of monaural noise, the BMLD, was 3 to 4 dB for the children and about 5 dB for the adults. However, part of that advantage in the children might have been due to learning, since the binaural mode was always presented after the monaural mode. Thus, there seems to be an age effect, also shown by Hall, Buss, Grose, and Dev (2004); although they used a 500 Hz tone in both ears with reversed phase in one ear. The binaural analysis starts when the signals reaches the superior olive complex. Here the brain can compare time and intensity differences between the ears. These analyses are crucial for the formation of BMLD. It seems clear that 5-year-old children have not reached the ability of adults to use binaural

Table 4. Mean 66.7 % thresholds in dB of the 3-word-utterances for the 5-year-old children (N=20). Means for adults measured with 5-word-sentences (Köbler, 2007), now adjusted to a threshold at 66.7 % correct words (see text), are shown within brackets (N=14).

	Monaural noise	Binaural noise	BMLD, dB
SM	-3.3 (-5.7)	-6.1 (-10,8)	2.7 (5,1)
FUM	-3.2 (-15,3)	-6.9 (-20,7)	3.8 (5,4)

cues. At birth the peripheral hearing is fully developed, but the myelin sheaths surrounding the nerve fibers continue to develop after birth. The velocity of the nerve signals depends on the thickness of the myelin sheaths. The precision of the nerve signal velocity might be a factor in the development of BMLD. Not until the upper teens does the nerve signal velocity between the hemispheres reach that of an adult (Boothroyd, 1997; Tonnquist-Uhlén, Borg, & Spens, 1995).

Comparison of boys and girls

Unexpectedly, the boys generally showed significantly better results than the girls. We found no publications confirming these results. Although there were unequal sample sizes, this should not result in statistical problems, since gender was the only between-subjects factor, and the ANOVA is very robust against possible unequal variances. Blandy and Lutman (2005) found no difference between 7-year-old boys and girls. However, Hagesäter and Thern (2004) showed similar results for Hagerman's 5-word-sentences in children 7 and 9 years of age. They hypothesized that the boys in the study guessed more than the girls. From our experience this explanation seems plausible. The girls seemed to be more afraid of guessing and increasing the risk of making an error. It is also possible that boys are more trained to listen in noise, since they often play in larger groups with more noise.

Future direction

There is a need to confirm these results with larger groups of children of different ages and with a more rigorous control of normal hearing status. Subsequently, the test material can be used for the assessment of children with hearing or language problems.

Conclusions

- The 5-year old children were able to perform the test with 3-word-utterances in noise.
- The results may be used as a preliminary reference material for 5-year-old children.
- The ability of our group of 5-year-old children to recognize the 3-word-utterances in noise was not as good as that of adults measured with 5-word-sentences, especially not in modulated noise.
- There was a significant gender difference, the boys having a significantly better mean speech recognition threshold in noise than girls, but the sample size was small and unequal between the two genders.
- The children had about 2 dB less BMLD than adults tested previously.

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