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Speech Intelligibility and Subjective Evaluation of Music Playback of Sound Transducers with Glass and Wooden Membrane

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Abstract: Novel state-of-the-art designer loudspeaker solutions offer "invisible audio" applications by applying a relatively small transducer onto glass or wooden plates, surfaces such as windows, tables, doors etc. Although manufacturers promise high quality transmission and good technical parameters, reliable measurement data do not exist. In our former evaluation, the SolidDrive system with glass membrane of different shapes, sizes, fixation methods was analyzed using vibration analysis, acoustic measurements and numerical simulations in COMSOL/FEM. This paper presents experimental results of standardized speech intelligibility measurements as well as subjective evaluation of the system.

Keywords: speech intelligibility, subjective evaluation, STI, sound transducer

1. Introduction

Loudspeakers in general are based on the same electromagnetic principle. A light weight membrane is moved by the coil oscillating in the magnetic field driven by the electric current. In order to avoid acoustic short circuits and to extend the frequency range, speakers are built into cabinets (closed, bass-reflex, loaded horn etc.). Newly designed solutions offer unconventional types of sound reproduction, often called "invisible audio" [1-3]. In this case, sound transducers of the same electromagnetic principle are manufactured and sold as stand-alone exciters without membranes. They can be attached to various surfaces, usually by gluing them on glass plates or screwing them on to wood, such as windows, tables, doors etc. This technique allows unique installations and applications by avoiding the need for large cabinets and by integrating the real sound source into or onto various equipment already installed in the environment. However, relatively low signal pressure levels (sensitivity), limited and unbalanced frequency response and high costs restrict their applicability to special needs, designer solutions and commercial purposes. Furthermore, manufacturers provide limited access to technical information and measurement results of technical parameters in their commercial literature, thus, it is difficult to decide whether a particular device is able to meet a customer's needs. The goal of our investigation was to test a commercially available transducer applied to various surfaces. This included vibro-acoustic measurements using multi-channel accelerometers, measurements of acoustic parameters and comparative evaluation based numerical simulation using FEM models in COMSOL [4,5]. As mentioned, there is only very limited technical information about the system. Most of the parameters cannot be measured without a membrane being attached to the transducer, so the general description of only the transducer of such systems – e.g. about frequency response or directional characteristics – does not provide reliably useful information. Acoustic and vibration measurements are time- and cost-expensive. Therefore, numerical simulations and FEM-based modelling seem to be an adequate alternative for estimating some of the technical parameters for real-life applications: the effect of membranes of different shapes, mass, material, fixing methods etc. can be evaluated without actual measurements.

The rest of the paper is organized as follows. Section 2 gives a short overview about the measurement setup including the objective and the subjective tests. Furthermore, the basic speech intelligibility tests are introduced for selection. Section 3 presents the results of the MRT, SIL and music transmission tests. Section 4 discusses the findings and future works will be highlighted in Section 5.

2. Measurement setups

2.1. Objective evaluation and former results

In our former study, in order to test the simulation method's reliability and the technical parameters in comparison the transducer was applied to various glass surfaces for vibration and acoustic measurements in parallel with a corresponding FEM simulation. Based on these studies, recommendations were given for applications comparing benefits and disadvantages [6-7]. These can be summarized as follows:

- Numerical simulation supports real measurement results, thus, estimations based on FEM modelling can be an alternative solution to measurements.
- Frequency response from 200 Hz – 10 kHz can be realized with almost plane wave propagation.
- The relatively low sensitivity limits the range of propagation and the SPL (nonlinear distortion).
- Placement of the transducer on the plate and fixation methods of the plane do not bias measurement results significantly.
- The system is not able to replace conventional loudspeaker setups if high quality playback is needed.

Figure 1 and 2 shows the SD1g transducer alone and applied on a glass membrane for the measurements.

Figure 1. The SolidDrive SD1g transducer

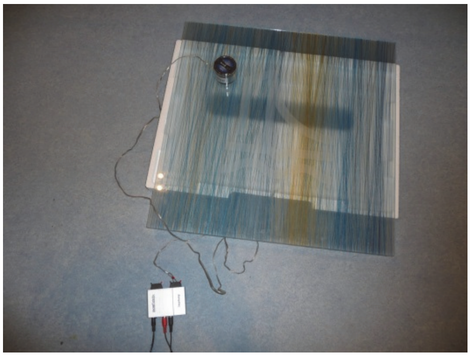

Figure 2. Initial setup for the transducer fixed on a glass plate and with a digital audio amplifier.

2.2. Subjective evaluation

Objective measures can predict musical and speech transmission quality of the system. Still, subjective evaluation of playback systems play a significant role in customers' judgments and selection criteria. The final step of this survey included the following evaluations:

- measurement of speech intelligibility (SI) based on standardized methods for German language in listening tests,
- estimation of the Speech Transmission Index (STI) based on Speech Interference Level (SIL) measurement and
- subjective evaluation of music playback with and without an additional subwoofer.

For the listening tests the following measurement setup was installed in an anechoic chamber. A formerly introduced glass plate of 76*76*0.8 cm (see Fig.2.) was placed on rubber legs in front of the listener. Simultaneously, another exciter of the same model was fixed by screws under the surface of a wooden table of 55*130*2.5 cm. A Yamaha DSP-A2 audio amplifier and a studio monitor loudspeaker for reference were used. Subjects were sitting on a comfortable chair at the table facing the glass plate and a tilted computer screen. They could respond via the screen by clicking with a wireless mouse. Figure 3 shows the installation. Signal level at the listening position was set to be equal for all three radiators at 65dB(A) L_{eq} using white noise. The level could be adjusted in 1 dB steps. 12 female and 20 male subjects participated between 16 and 35 years (mean 24) in 30-minute sessions.

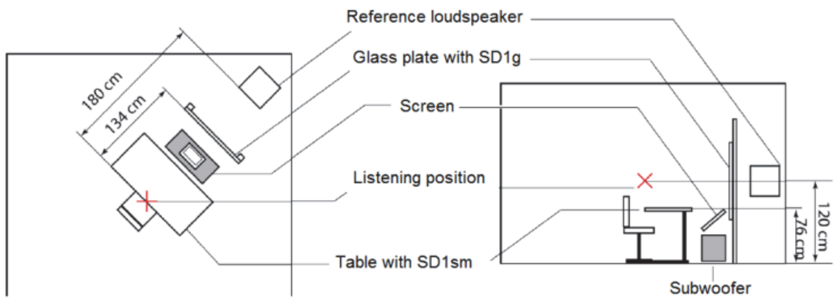

Figure 3. Schematic figure of the setup from above (left) and from the side (right).

For the music test, an additional closed-type subwoofer of 15 litres volume was installed under the table that could be switched on and off by the subject. One session included three one-minute tracks with 10 seconds of intermission. All three tracks were played back for every listener twice (on glass and on wood). These three tracks were selected to represent different bass content, characteristics and tonality of female voices.

Track1: Lena Mayer Landrut – "I like to bang my head" (bass and voice in balance)

Track2: Katie Melua – "Spider's web" (more voice)

Track3: Drum/percussion recording (more bass, no voice)

Figure 4 shows the transfer characteristics of the wooden table with and without subwoofer support. As expected, the low frequency region between 30-80 Hz can be amplified by the subwoofer.

2.3. Speech Intelligibility

Speech intelligibility (SI) can be measured with different methods, usually in the frame of room acoustics and clinical audiology [8-10]. SI is a number between 0-100% and it is different for one syllable, multiple syllable words or sentences. The quality of the speech signal, transmission, subject group etc. also influence the results. Subjective tests can be 'open' where perceived words have to be repeated by the listener or 'closed' where listeners select from a collection of possibilities (forced choice). Table 1 shows comparative summary of different measurement methods corresponding to subjective levels on the left. In medical audiology only subjective testing methods are used targeting the determination of the speech intelligibility threshold, that is, the SPL (dB) where intelligibility is 50%.

Table 1. Comparison of different SI measurement methods (DIN EN ISO 9921-2003). Corresponding to the best STI level, a 98% rate of a MRT is needed.

Classification	**Sentence (%)**	**Words, MRT (%)**	**CVC Words (no meaning) (%)**	**STI**	**SIL (dB)**
excellent	100	> 98	> 81	> 0,75	21
good	100	93-98	70-81	0,60-0,75	15-21
acceptable	100	80-93	53-70	0,45-0,60	10-15
poor	70-100	60-80	32-53	0,30-0,45	3-10
insufficient	< 70	< 60	< 31	< 0,30	< 3

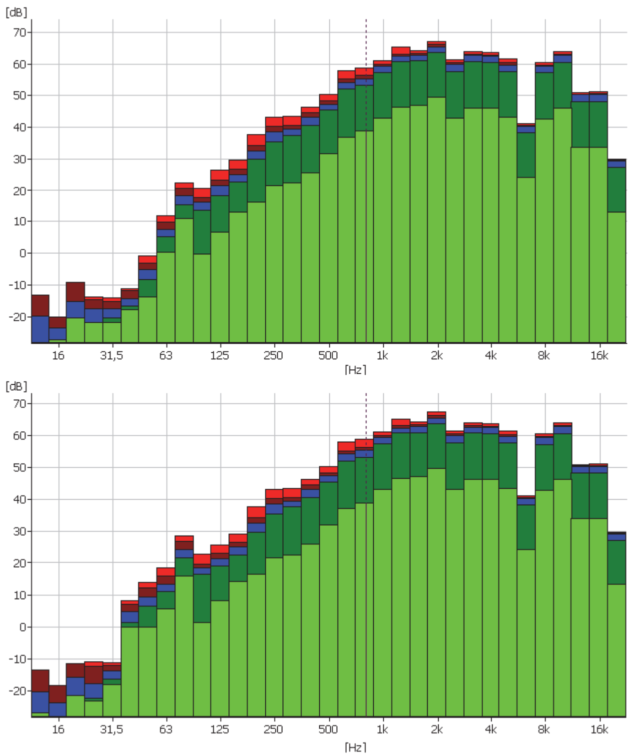

Figure 4. Transfer characteristics of the exciter fixed on the wooden table without (upper) and with subwoofer support (lower). The frequency range between 30-80 Hz is elevated.

Several standardized tests exist for subjective measurement for German language, for example the *Freiburger* test uses 20 one-syllable words and 10 lists containing 10 numbers [11,12]; the *Marburger* test for children [13,14]; the *Göttinger* test with meaningful sentences created from 5 words [15,16] or the *Oldenburger* test with meaningless sentences [16-18]. Based on different considerations and limitations of the measurement system and procedure the so called *Modified Rhyme Test (MRT)* was selected for the subjective evaluation [19,20]. It uses six-word lists of rhyming or similar-sounding monosyllabic words. Each word is constructed from a consonant-vowel-consonant (CVC) sound sequence, and the six words in each list differ only in the initial, the final consonant sound or the vowel. Listeners are shown a six-word list and then asked to identify which of the six was spoken. A carrier sentence can be also used. MRT test results indicate errors in discrimination of both initial and final consonant sounds. Listener responses can be scored as (1) the number of words heard correctly, (2) the number of words heard incorrectly or (3) the frequency of particular confusions of consonant sounds. Examples for German, English and Hungarian MRT lists can be seen in the appendix. In our test, the German database was used assisted by a user interface from the University of BTU Cottbus that is free to download [21]. Figure 5 shows a screen-shot of the application. For recording the speech database, all words were read seven times by a native German male speaker and the best examples were selected for the test after normalizing the levels. Every subject received a 24-word list four times, using glass and wood, and with a low and a high presentation level respectively.

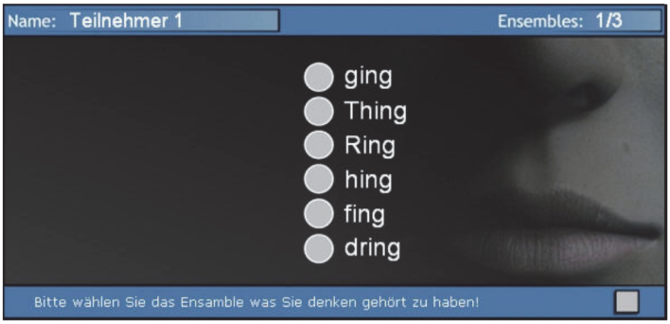

Figure 5: Screenshot of the Simasoft application [21]. The application has also built-in statistics for SI and weighted SI.

There is also a language independent objective measurement for speech intelligibility estimation, called Speech Transmission Index (STI) and Speech Interference Level (SIL) [22-28]. For the STI measurement, loudspeakers and microphones are needed. Excitation signals contain seven octaveband noises between 125 Hz and 8000 Hz, amplitude modulated by a modulation signal of 0,63-12,5 Hz. The STI is recommended if the transmission properties of the playback system and background noise, echo have to be taken in account. In case of room reverberation time less than one second, the STI can be calculated from the measured SIL as follows:

$$4\ \mathrm{STI} = (0{,}1\ \mathrm{SIL} + 0{,}9) \qquad (1)$$

For the SIL measurement the same pre-recorded speech signals were used. During the measurement, a presentation level varying from 20 to 65 dB was set and the resulting STI estimation was plotted directly. Due to the anechoic environment in our measurement setup, the STI could be calculated based on the SIL measurement.

3. Results

3.1. Modified Rhyme Test

For the MRT test, the German wordlist was selected (see Appendix). In contrast to the English test and other wordlists, this contains 5-word sub-lists. In order to reduce the probability of guessing in case of misunderstanding, the sixth possibility was set to "no answer". In the case of 6-word lists, subjects click an answer if they are not sure with a probability of 1/6. Thus, results are usually re-calculated and weighted using different methods. In our case, this was avoided by introducing this sixth possibility. For control purposes, a short white noise signal was also played back randomly in the tests. During the test 1691 false answers were recorded and from this subjects selected "no answer" only 686 times. On the other hand, if the white noise sample was used, subjects never clicked any of the word options, so white noise was really easy to detect.

Table 2 shows mean values and standard deviations for all three radiators for the initial, final consonant and the vowel. The last column shows the weighted (corrected) values. The relatively large standard deviation is due to the short wordlist and low presentation level.

Table 2. Mean and STDV values for all three radiators for high presentation level (top) where intelligibility is between 50-100% and for low presentation level (bottom) where intelligibility is lower than 50%. LS is studio reference monitor, SDg is a glass and SDh, a wooden membrane.

	SI (%)	initial	middle	final	Weighted SI
LS	Mean	55,56	84,58	64,61	68,25
SDg		67,35	83,91	67,84	73,04
SDh		66,74	88,94	68,64	74,77
LS	Stdv	22,57	18,45	20,66	40,80
SDg		19,23	18,53	18,85	10,49
SDh		18,46	11,24	18,49	10,21
LS	Mean	17,55	47,93	26,26	30,58
SDg		9,06	44,30	19,81	24,39
SDh		23,03	42,60	29,29	38,24
LS	Stdv	14,23	21,50	17,59	11,95
SDg		14,56	28,32	17,67	13,25
SDh		22,70	23,15	16,48	14,20

If the presentation level is high enough for the weighted SI to be greater than 50%, the vowel component can be recognized easily. Furthermore, there is no significant difference between the initial and final consonants. Comparing weighted SI values of 73,04% with 74,77% there is no benefit for any of the SD transducers and the results are only slightly below the results of the studio reference loudspeaker. If presentation level is low and SI is below 50%, differences become greater. Although the vowel can be recognized the best, rates are much lower than previously. Furthermore, the final consonant can be recognized better than the initial one, especially with glass. The summarized comparison shows a much better performance for the weighted SI using wood (38,24%) than glass (24,39%). Wood was even superior to the reference loudspeaker.

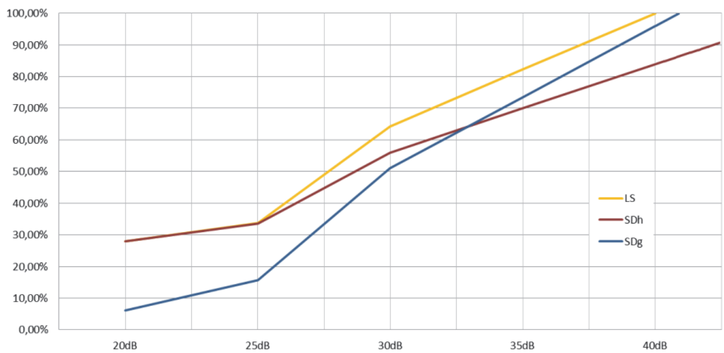

Figure 6. SI as function of presentation level of the reference loudspeaker (yellow), transducer on glass (blue) and transducer on wood (red).

Using all radiators in the MRT, the 98% intelligibility rate could be achieved using wood as membrane at 45 dB(A) SPL and using glass at 41 dB(A) indicating no significant difference between these mediums (Fig. 6).

3.2. SIL measurement

During the objective measurement, the SIL (and thus, the STI) increases rapidly as SPL increases from 20 dB(A) to 65 dB(A). An STI of 0,75 is reached at 47 dB(A).

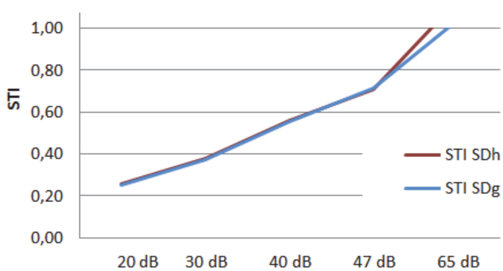

Figure 7. Curves of SLI transformed to STI values as function of presentation level.

At higher presentation levels, wood performed somewhat better than glass. As expected, standard deviations are higher at lower signal levels. Both SIL and calculated STI increase rapidly above 30 dB(A). These results are in agreement with the MRT results.

3.3. Music transmission

The evaluation of overall music transmission quality was based on a ranking in five steps where 1 point corresponds to “insufficient”, 2 to “poor”, 3 to “acceptable”, 4 to “good” and 5 to “excellent”. Bass transmission, however, used only three steps from 1 to 3 points.

In overall quality based on all tracks, glass was superior to wood, being “above average” for about 70% of the listeners. The same evaluation for wood showed a result of 45% and “average” was selected most frequently.

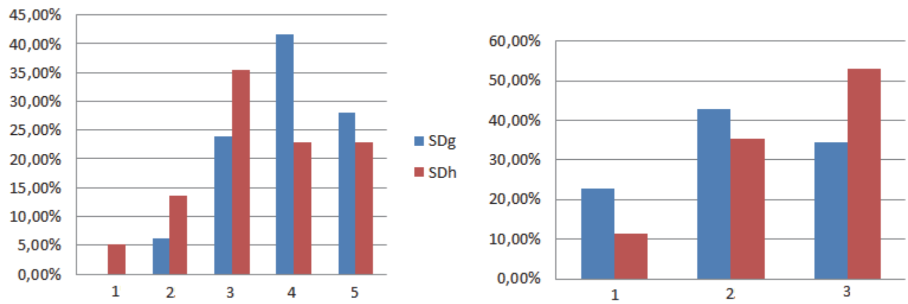

Figure 8. Relative frequency of answers for overall quality (left) and for bass transmission (right) for glass (blue) and wood (red).

In bass quality wood was superior to glass without subwoofer support. Wood was classified as excellent for about 52% as long glass was only for 33%. 45% of the listeners would suggest subwoofer extension in case of wood, and 60% would suggest it in case of glass. Asking an informal question, users suggested they would even pay extra money to have subwoofer extension. Results depend on the tracks: more bass content in the music (track3) reveals the subjective need for subwoofer support.

4. Discussion

Speech intelligibility tests usually target subjects instead of equipment. This means, one subject will be evaluated using different presentation methods of speech samples, so focus is on the abilities of the subject. In our case the opposite happens, the sound transmission quality of a transducer was evaluated by several subjects for whether or not it is able to produce good speech and music transmission.

In the subjective MRT wood performed better than glass if the signal level (thus, the signal-to-noise ratio) was low. With an appropriate signal level, both performed almost equally as well and the studio reference loudspeaker in the anechoic environment. The 98% SI could be reached around 40-45 dB signal level and also the estimated STI for excellent values was around 47 dB. In summary, for speech transmission, a signal-to-noise ratio greater than 50 dB would result in a sufficient SI supporting the manufacturer’s claim.

There was also no significant difference between the membranes during music playback. Although they produce relatively low sound pressure levels and they cannot overperform high quality loudspeakers, it is an acceptable option for short distance radiation, such as sitting at a table or near to a window. Using a subwoofer extension may increase the subjective impression further.

It was interesting that subjects reported to be able to detect the location of the transducer on the vibrating plate. They could actually hear where the transducer was placed (screwed) on the table from below. However, this fact did not influence their judgments.

Although not used in the current evaluation, the Hungarian word list was developed based on the German test. In order to represent the relative frequency of the consonants and vowels related to Hungarian language word lists shorter than 5 words are also included. A test using this list, however, would need different presentation and evaluation methods as it differs from the usual MRT lists.

Beside the numerous advantages of this loudspeaker system, some disadvantages have to be listed as well. Independent of the membrane's material we get high costs, low sound pressure levels, fluctuating transfer function and low transmission below 200 Hz and above 12 kHz. Although not measured directly, if the radiated sound was set to "comfortably loud", non-linear distortions of the transducer and the vibrating surface become audible. The vibrating transducer can be easily overdriven. Furthermore, installation of multiple transducers on the same surface can have unexpected effects due to interferences, standing waves etc., and stereo or multi-channel transmission may not be applicable.

5. Future work

Future work includes comparative evaluation of intelligibility of German and Hungarian speech samples. It is expected that using the same testing method no significant difference will appear, that is, databases of results can be merged and evaluated combined, furthermore, that the Hungarian corpus for this test can be used in other similar tests in the future. The sound data base containing these words will be recorded by a native Hungarian speaker as high quality mono sound samples.

As an informal study, future work includes the system installed for a longer time period on a shop-window in a crowded pedestrian zone in the city center. The window will be used as membrane "speaking" to pedestrians and customers, airing some kind of commercial. Shop assistants and customers will be interviewed about this potential solution.

6. Conclusion

Transmission quality of sound transducers applied on wooden and glass membranes was evaluated based on objective and subjective measures. The objective measurement included a SIL measurement installed in the anechoic chamber. From this, STI estimation could be made resulting in a satisfactory value of greater than 0,75 in case of a presentation level of more than 47 dB. The subjective evaluation using the modified rhyme test in German language supported these results as 98% of SI could be reached at 41 dB and 45 dB respectively. It can be concluded that an overall signal presentation level about 45-50 dB greater than background noise could be sufficient in non anechoic environments as well. This signal-to-noise ratio can be achieved in indoor environments.

Using three different one-minute music samples of different genres and bass content, both membranes were judged as average or better for music transmission even without an additional subwoofer support. Although glass performed somewhat better in overall music quality than wood, focusing on bass transmission, wood was better. A subwoofer extension for a better bass quality is suggested.

This study was aimed at a subjective evaluation that extended former objective acoustic and vibration measurements and numerical simulations. Summarized results support the manufacturer's recommendations and measurement results by offering alternative sound production solution if "invisible audio" issues are present.

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Appendix

Examples of the German, English and Hungarian rhyme test corpus can be found in Table 3-7. The Hungarian version was created based on similarly to the German version according to the Hungarian speech databases and distribution values of the vocals [29]. Because some rare vocals could not be represented in equal number to the most frequent ones, some lines and examples may contain fewer words than the German version. This Hungarian word list can be used as a test material for further measurements and test.

Table 3. Wordlist of the German 'WAKO' one-syllable rhyme test used for the tests [29]

Nr.	Anlautteil				
1	Sinn	hin	bin	Zinn	Kinn
2	fiel	schiel	Ziel	Kiel	Nil
3	doch	poch	noch	Joch	Loch
4	sehn	den	Gen	zehn	lehn
5	wisch	Fisch	Tisch	zisch	misch
6	Saum	Schaum	Zaum	kaum	Raum
7	wir	vier	Pier	Tier	mir
8	sahn	Bahn	Zahn	mahn	Lahn
9	sät	tät	näht	jät	rät
10	hieß	dies	gies	nies	ließ
11	sehr	Teer	zehr	Meer	leer
12	Wut	gut	Nut	Ruth	lud
13	Tag	mag	nag	jag	rag
14	vor	gor	Tor	Moor	Rohr
15	weil	Seil	peil	Teil	Zeil
16	Haus	Gauß	paus	raus	Laus
17	Schein	dein	mein	nein	rein
18	war	gar	Kar	Jahr	rar
19	weiß	beiß	Geiß	Reis	leis
20	fad	bat	Tat	Naht	Rat
21	Fund	Schund	Hund	Mund	rund
22	vorn	Born	Dorn	Zorn	Korn
23	wumm	summ	dumm	Mumm	Rum
24	Sicht	dicht	Gicht	nicht	Licht
25	Haff	baff	gaff	Kaff	raff
26	Schuß	Bus	Guß	Kuß	Nuß
27	sind	find	schind	bind	Rind
28	wenn	Fenn	denn	nenn	renn
29	säng	häng	peng	meng	läng
30	was	Haß	das	Paß	naß
31	Fest	best	Test	Nest	Rest
32	wann	dann	Tann	Mann	ran
33	Wacht	dacht	Macht	Nacht	Jacht

	Vokalteil				
34	schief	Schiff	Schaf	schaff	schuf
35	Mehl	Mal	Moll	Mull	Müll
36	Wild	Wald	wählt	Welt	wühlt
37	Wind	Wand	wohnt	wund	wähnt
38	bis	Baß	Bus	büß	bös
39	seht	Saat	satt	sät	Süd
40	hin	Hahn	Hohn	Huhn	höhn
41	wieg	Weg	wag	wog	wäg
42	hier	Heer	Haar	Herr	hör
43	Kien	Kinn	Kahn	kenn	kühn
44	dir	der	Dur	dürr	dörr
45	biet	bitt	Beet	Bett	böt
46	lieg	leg	lag	Leck	lüg
47	viel	fehl	Fall	Fell	füll
48	Ritt	Reet	rot	rät	rett
49	Sinn	sehn	sann	Sohn	Senn
50	Stiel	still	Stahl	Stall	stell
51	Trieb	Trip	trapp	Trupp	trüb
52	back	Bock	bück	bög	Böck
53	schiel	Schill	Schall	scholl	schäl
54	Mist	Most	mußt	meßt	müßt
55	Rist	Rost	Rest	rüst	röst
56	trief	triff	traf	troff	Treff
57	sind	sehnt	Sand	Sund	send
58	Hieb	heb	hob	Hub	hupp
	Auslautteil				
59	reif	reib	reit	Reim	Rhein
60	Muff	muß	Mumm	murr	Mull
61	Mief	mies	miet	mim	mir
62	Weg	wem	wen	Wehr	web
63	nach	Naab	Naht	nag	nahm
64	Ruf	Ruß	Ruch	Ruhm	Ruhr
65	rauf	raus	Rauch	Raub	Raum
66	Los	Lob	Lot	log	Lohn
67	des	Depp	Deck	dämm	denn
68	Saat	sag	sahn	Saar	Saal
69	schief	schieß	schied	schien	schiel
70	Graf	grab	Grat	Gram	Gral
71	weiß	Weib	weit	Wein	weil
72	Hof	hoch	hob	Hohn	hohl

Table 4. The 300 Stimulus Words of the MRT

1		went		sent		bent		dent		tent		rent
2		hold		cold		told		fold		sold		gold
3		pat		pad		pan		path		pack		pass
4		lane		lay		late		lake		lace		lame
5		kit		bit		fit		hit		wit		sit
6		must		bust		gust		rust		dust		just
7		teak		team		teal		teach		tear		tease
8		din		dill		dim		dig		dip		did
9		bed		led		fed		red		wed		shed
10		pin		sin		tin		fin		din		win
11		dug		dung		duck		dud		dub		dun
12		sum		sun		sung		sup		sub		sud
13		seep		seen		seethe		seek		seem		seed
14		not		tot		got		pot		hot		lot
15		vest		test		rest		best		west		nest
16		pig		pill		pin		pip		pit		pick
17		back		bath		bad		bass		bat		ban
18		way		may		say		pay		day		gay
19		pig		big		dig		wig		rig		fig
20		pale		pace		page		pane		pay		pave
21		cane		case		cape		cake		came		cave
22		shop		mop		cop		top		hop		pop
23		coil		oil		soil		toil		boil		foil
24		tan		tang		tap		tack		tam		tab
25		fit		fib		fizz		fill		fig		fin
26		same		name		game		tame		came		fame
27		peel		reel		feel		eel		keel		heel
28		hark		dark		mark		bark		park		lark
29		heave		hear		heat		heal		heap		heath
30		cup		cut		cud		cuff		cuss		cud
31		thaw		law		raw		paw		jaw		saw
32		pen		hen		men		then		den		ten
33		puff		puck		pub		pus		pup		pun
34		bean		beach		beat		beak		bead		beam
35		heat		neat		feat		seat		meat		beat
36		dip		sip		hip		tip		lip		rip
37		kill		kin		kit		kick		king		kid
38		hang		sang		bang		rang		fang		gang
39		took		cook		look		hook		shook		book
40		mass		math		map		mat		man		mad
41		ray		raze		rate		rave		rake		race
42		save		same		sale		sane		sake		safe
43		fill		kill		will		hill		till		bill
44		sill		sick		sip		sing		sit		sin
45		bale		gale		sale		tale		pale		male
46		wick		sick		kick		lick		pick		tick
47		peace		peas		peak		peach		peat		peal
48		bun		bus		but		bug		buck		buff
49		sag		sat		sass		sack		sad		sap
50		fun		sun		bun		gun		run		nun

Table 5. The Hungarian corpus for MRT – 1

1.	bak	rak	lak	jak	csak	(vak, nyak)
2.	far	kar	mar	tar	var	
3.	bab	hab	rab	zab		(tab)
4.	fagy	hagy	nagy	vagy	zagy	
5.	dúl	gyúl	múl	nyúl	túl	(fúl)
6.	bér	dér	fér	kér	mér	(vér)
7.	bor	kor	por	sor	szor	(tor)
8.	bél	cél	dél	fél	szél	(gél, kél, nyél, tél, vél)
9.	bőr	szőr	Győr	tőr	kőr	(csőr)
10.	bal	dal	fal	hal	nyal	
11.	bír	hír	nyír	pír	sír	(szír, zsír)
12.	bók	csók	jók	pók	szók	
13.	hús	bús	dús	szús		(kús)
14.	búr	dúr	fúr	szúr	túr	(zsúr)
15.	bár	cár	már	kár	nyár	(gyár, jár, pár, sár, tár, vár)
16.	bál	tál	sál	hál	nyál	
17.	csűr	kűr	szűr	tűr	zűr	
18.	fát	gát	lát	hát	tát	
19.	búg	húg	lúg	rúg	súg	(zúg)
20.	cser	per	ver	mer	nyer	(szer, jer)
21.	kel	lel	jel	nyel		
22.	kell	mell	Tell	Bell		
23.	hall	vall	gall			
24.	szenny	genny	menny	kenj	menj	
25.	matt	katt	patt	csatt	jatt	
26.	sakk	pakk	cakk	makk	lakk	(fakk, vakk)

Table 6. The Hungarian corpus for MRT – 2

1.	bak	buk	bók	bök	búk	
2.	lap	láp	lep	lép	lop	
3.	kar	kár	kér	kűr	kór	(kör, kőr)
4.	mar	már	mér	mer	mór	
5.	tar	tár	tor	tér	tűr	(tőr)
6.	bár	bér	bor	bór	bőr	
7.	tál	tél	tol	tel	túl	
8.	fal	fel	fél	fúl	fül	
9.	pár	por	per	pír	pér	
10.	rag	rág	rúg	rég	rög	
11.	var	vér	ver	vár		
12.	vaj	váj	vej			

Table 7. The Hungarian corpus for MRT – 3

1.	báb	báj	bál	bán	bár	
2.	gél	gém	gén	gép	géz	
3.	fém	fél	fék	fér	fény	
4.	táv	tán	tár	tál	táp	
5.	tény	tér	tép	tét	tél	
6.	szem	szel	szer	szesz	szenny	
7.	len	les	lesz	lep	lel	(leg, LED)
8.	góc	gój	gól	gót	gór	
9.	szám	szár	száz	szák	száj	(szád, szász)
10.	mák	már	más	máz	máj	(mál)
11.	rám	rád	rác	rák	ráz	(rát, rág)
12.	csak	csal	csat	csap	csaj	
13.	dúc	dúl	dúr	dús		
14.	hab	had	haj	hal	has	
15.	jel	jem	jen	jer	jegy	
16.	kéj	kél	kém	kén	kér	
17.	pék	pép	Pér	pénz	Pécs	
18.	rég	rém	rés	rész	rét	(rév, réz)
19.	vad	vaj	vak	van	var	(vas)
20.	kés	kéz	kép	kész	két	
21.	csel	csen	cser	csepp		