Determination of Hearing Dimensions and their Relations to Psychoacoustic Descriptors

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Summary: A listening test using the semantic differential and a subsequent factor analysis is applied to determine basic hearing dimensions. Based on the results of a previously conducted survey of sound attributes the selection of attributes and environmental sounds was optimized. The relation between the results of the listening test and the psychoacoustic descriptors calculated from the sounds were evaluated using an analysis of correlation. The calculation algorithms for loudness and sharpness are in good agreement with the outcome of the listening test. For roughness and fluctuation strength the calculation algorithms need to be improved for being applicable to environmental sounds.

INTRODUCTION

For determining hearing dimensions one possible way, as introduced by Solomon [7], is the realisation of a listening test using the semantic differential and a subsequent factorial analysis. This method is quite popular when dealing with the sound quality of products [4, 5, 8]. Important for the success of this method however is the choice of attributes and sounds for the listening test.

For the purpose here a survey of sound properties was performed prior to the main test, which by means of a cluster analysis led to a selection of prototype sounds and attributes. The sounds were binaurally recorded and presented to the subjects in the main listening test for evaluation. The results were used to examine relationships with psychoacoustic descriptors. The descriptors were developed mainly using artificial and stationary sounds and need to be validated for the application on environmental sounds.

SURVEY ON SOUND PROPERTIES

By means of the survey three aims had to be accomplished. First, a large number of different sound properties had to be considered. Second, in order to limit the scope of the listening test the attributes related to the same sound property had to be examined and the most characteristic had to be chosen for each property. Third, pairs of attributes and sounds had to be determined for the main listening test.

To achieve the first aim 29 sound properties and 154 matching attributes were collected from appropriate publications [2, 3, 4, 5, 7, 8]. They were presented to a jury of 17 adults,

TABLE 1: Results of the cluster analysis as performed on the frequency of the subject answers. The sound properties are aggregated to 12 clusters.

Cluster-Nr.	Sound properties	Cluster-Nr.	Sound properties
1	Pitch Strength, Tonality, Superiority	7	Dangerousness, Intrusiveness, Sharpness
2	Density, Fullness	8	Loudness, Power
3	Roughness	9	Noisyness, Annoyance
4	Tension, Impulsiveness, Nearness	10	Beauty, Pleasantness, Comfortableness
5	Livelyness, Fluctuation Strength	11	Transparency, Clarity
6	Hardness, Metallic Factor	12	Deepness, Brightness, Dullness, Heaviness

TABLE 2: Z-transformed results of the listening test. Judgements in direction of the attributes of the bottom row have negative z-values. Z-values above 1 are marked dark grey, z-values under -1 light grey. Values between -0.35 and 0.35 have been omitted.

clusternumber	1		2		3		4		5		6		7		8		9		10		11		12	
sounds	harmonic	full of character	compact	rich	rough	scratching	exciting	close	dynamic	fluctuating	metallic	angular	sharp	screeching	loud	powerful	desirable	pleasant	comfortable	beautiful	clear	distinct	high	dull
church bells	1,1	1,0	-0,4	0,7	-0,9	-1,0	-0,4	-1,1	0,4	1,0	0,8	-0,8	-0,4		0,7	0,8		0,5	0,5	0,8	0,6	0,7		-1,3
fan		-1,1		-0,8				-0,7	-1,5	-1,5			-0,7		-0,6	-0,8	-0,4	-0,5	-0,4	-0,6	-1,0	-0,8		0,4
football stadium	-0,9		0,5	1,2	0,7	0,4	1,4	0,7	0,4		-0,4			1,2	1,5	1,2	-0,6	-0,9	-0,8	-0,7	-1,0	-0,8		
concourse			-0,9	0,9		-0,4					-0,5		-0,7			-0,5					-0,6	-1,2	-0,4	
adhesive tape			0,4		0,8	0,9		0,5					0,6	0,6										
tyre on gravel	0,5		-1,0		0,4		-1,4				-0,4			-1,2	-1,5	-1,2	1,1	1,1	1,0	0,9	-0,4	-0,5	-0,4	0,5
hooves	0,7	0,8	-0,9	0,5	-0,4		-1,3		0,6					-0,8			1,2	1,3	1,1	1,1	0,5	0,4	-0,4	
typewriter	-0,4	0,5		-0,6	-0,5			0,4		0,4	0,4	1,3	0,6								1,0	1,1		
wasp	0,4	0,5	-0,7			0,4	0,4	1,3	0,8	1,1	-0,4				-0,9	-1,2	-0,5	-0,4	-0,6			0,4		
yelling children		0,4	-1,1		-0,6			-1,2	0,7	0,9				0,9	-0,4	-0,5					0,5		1,1	-0,6
howling wind	0,9				-0,4	-1,2	-1,1	-1,3			-0,5	-1,0	-0,6	-0,8	-1,5	-1,5	0,9	0,7	0,5	0,8	-0,7	-0,7	-0,4	0,5
sledgehammer			0,8	-0,7	-0,5		0,5	0,4			1,5	1,4	0,7	0,5	0,7	0,8	-0,7	-0,6	-0,6	-0,5	1,0	0,9	0,9	-0,8
tin can	-0,9		-0,5			0,7			0,5	0,7	1,1	1,5	0,7				-0,4	-0,4		-0,5	0,6			
dentist drill	-1,0	-0,4			0,7	0,9	1,0	0,8			0,6		1,0	1,5	0,5	0,4	-1,3	-1,4	-1,4	-1,4			1,4	
circular saw	-1,3	-0,4	0,8		1,0	1,6	1,4	0,5	-0,5	-0,8	1,3	0,8	1,4	1,8	1,4	1,2	-1,3	-1,4	-1,4	-1,5		0,5	1,1	-0,5
compressed air	-1,2	-1,0	0,4	-0,6	0,7	1,3	1,1	0,7	-0,7	-1,0		0,6	1,2	1,0	0,6	0,5	-1,2	-1,2	-1,3	-1,3			1,0	
waterfall		-0,4	0,4	0,4	1,2	0,6		0,4	-0,5	-1,0	-0,6				1,0	1,1					-1,0	-1,1	-0,5	0,8
ship´s horn		0,9	1,1	0,5	0,5			-1,0	-0,5	-0,6	-0,8	-0,5	-0,5		1,2	1,5					-0,5	0,4	-1,5	
traffic noise	-0,7	-0,4		0,5	0,7		0,6				-1,1	-0,4	-0,6		0,8	0,5	-1,0	-0,9	-0,8	-0,8	-1,2	-1,0	-1,3	0,8
ocean noise	0,8	0,4	-0,6	0,5	0,5		-1,4	-0,8			-0,6	-0,9		-1,2			1,5	1,4	1,5	1,3	-0,5	-0,6	-0,4	0,5
"klangschale"	1,5	0,8		0,4	-1,5	-1,4	-1,1				0,9	-1,4	-0,5	-1,1			0,8	1,1	1,0	1,2	1,2	0,9		-1,4
ringing glass	1,1			-0,7	-1,2	-1,1	-0,4				0,8	-0,5		-0,8	-1,1	-0,9	0,9	0,8	0,8	0,8	1,5	0,8	0,9	-1,5
stone in well			0,4	0,5		-0,5			0,7	0,8	-1,1	-0,6	-1,1	-0,5			0,6	0,5	0,5	0,5	-0,4		-1,4	0,9
tiny bell	0,6			-1,2	-1,0	-0,5					1,4		0,8		-0,5	-0,8					1,4	1,0	1,2	-1,3
rubber hammer		-1,2	0,9	-1,7			-0,4		-0,6		-1,8		-1,8	-0,8	-1,1	-0,5					-0,7		-1,3	1,9
	inharmonic	without character	relaxed	plain	smooth	gliding	calming	far	static	steady	dull	round	blunt	calming	quiet	weak	undesirable	unpleasant	uncomfortable	ugly	dim	vague	deep	tingling

who had the task to relate the attributes to each of the sound properties. In addition, the members of the jury were encouraged to mention typical sounds for certain properties.

In the second step a cluster analysis was employed combining the 29 properties to 12 property clusters (tab. 1). The frequency of designations of the attributes within each cluster was taken to select 24 pairs of attributes, i. e. two for each property cluster. Only those attributes that had high frequencies and high peculiarity on the corresponding property cluster where selected. When entered in a table in order of the representing clusters the frequency of the attributes results in a diagonal structure. The selection of the 25 prototype sounds followed the same procedure (they can be depicted from tab. 2).

LISTENING TEST

The selected sounds were recorded on DAT-cassette using an artificial head (Head-Acoustics). The sounds were presented to the subjects with original loudness via headphone amplifier (Head-Acoustics) and electrostatic headphones (STAX). Twenty adults with normal hearing judged the sounds on the selected pairs of attributes using a seven-category-scale semantic differential. Prior to the analysis all subjective data was standardised in order to account for the particular behaviour of each subject. The mean of the z-values for each sound is shown in tab. 2 for all attributes. Since the sounds are arranged in order of the corresponding attributes high ratings on the diagonal can be observed. This result confirms the choice of the sounds as representatives for the selected attributes. Only 3 sounds do not meet this expectation: *gravel*, *typewriter* and *howling wind* which have lower mean ratings than an absolute z-value of 0.35 for the expected attributes.

The highest z-values are obtained for the sound *rubber hammer*, which is the the most dull (1.85) and least metallic (-1.81). The requested peculiarity of the selected attributes and sounds was not achieved. Nearly all sounds have additional high ratings on attributes other than the representatives. The sounds *dentist drill*, *circular saw* and *compressed air* especially show high ratings for other than the selected attributes sharp and screeching.

In order to reduce the amount of data and to extract relevant information from the data a principle component analysis (PCA) and a consequent varimax rotation was applied to the z-transformed values of the attributes used during the listening test. The analysis extracted 6 factors covering 72.4% of the total variance in the data. Factors with an eigenvalue less than 1 were not considered. The KMO criterion has a value of 0.91 which can be regarded as an exceptional result. The relative high number of 6 extracted dimensions with respect to 24 variables can be seen as an outcome of the broad selection of sounds and attributes. The factors were named using the attributes with highest factor loadings: pleasant, metallic, scratching, powerful, fluctuating and distinct (fig. 1).

The results of the factorial analysis are in good agreement with other studies. The factors pleasant, powerful and metallic are well-known results of studies using the semantic differential [3, 4, 5, 6]. Roughness (factor scratching) and fluctuation strength are psychoacoustic entities [9]. The attributes used as a descriptor for sharpness (sharp and screeching) are divided between the two factors metallic and pleasant. This indicates the connection between the psychoacoustic sharpness and the sensory pleasantness of sounds [1].

ANALYSIS OF CORRELATION

For prediction purposes the relationships between the attributes and factors on the one hand and psychoacoustic descriptors on the other hand were examined. Psychoacoustic descriptors (loudness, sharpness, pitch strength, roughness and fluctuation strength) and intensity parameters were calculated using the BAS System Version 4.4 (Head-Acoustics). Several percentiles were determined for each quantity. Pearson's correlation coefficients were calculated between the percentiles, the factors and all attributes. The results are shown in tab. 3 for those attributes, where the highest correlation coefficients occured. The judgements on loudness, sharpness and pitch strength attributes and the corresponding factors are highly connected to the equivalent descriptors. The calculated roughness shows little correlation with the factor scratching but none with the corresponding at-

FIGURE 1: Squared factor loadings of the z-transformed listening test data. Attributes with negative factor loadings are marked with an asterisk.

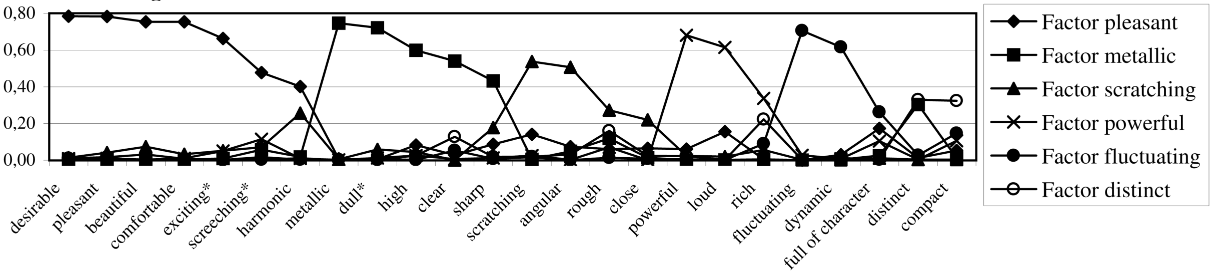

TABLE 3: Significant Pearson's correlation coefficients between factor values or selected attributes and psychoacoustic descriptors. Factors are printed in capitals. High significant coefficients are printed bold. Cells are marked grey, where the descriptors and attributes match.

Descriptor	PLEASANT	screeching	harmonic	METALLIC	metallic	dull	clear	sharp	SCRATCHING	rough	scratching	angular	POWERFUL	loud	powerful	DISTINCT	distinct
Loudness		**0,65**	-0,40					0,50		**0,57**	0,42		**0,90**	**0,88**	**0,89**		-0,46
Sharpness	**-0,51**	**0,71**	**-0,72**	**0,51**	**0,53**			**0,82**	**0,72**	**0,57**	**0,79**	**0,69**		**0,53**	0,47		0,40
ToneToNoise			**0,58**	**0,58**	**0,56**	**-0,77**	**0,63**		**-0,65**	**-0,72**	**-0,57**	**-0,53**				0,41	**0,59**
PromRatio			**0,51**	**0,67**	**0,59**	**-0,78**	**0,73**			**-0,72**	-0,50						**0,57**
Roughness							0,45		**0,54**			**0,66**		**0,66**	**0,60**		0,43
Modulation									**0,59**			**0,69**	**-0,54**			0,46	
FluctuationStr		0,44										0,47		**0,74**	**0,77**		
Impulsiveness					0,48		**0,54**		**0,61**			**0,70**				**0,51**	0,49

tributes rough and scratching. There is no correlation between the calculated fluctuation strength and corresponding attributes or factor fluctuating.

CONCLUDING REMARKS

The selection of attributes which match the sounds to be used in the listening test is an adequate method to ensure optimal results. Due to the broad selection of environmental prototype sounds this study yields an unusual high number of factors. In comparison to other studies, where usually the factors pleasant, metallic and powerful were obtained, this investigation produces two additional factors scratching and fluctuation strength as hearing dimensions for environmental sounds.

However, except for the calculated loudness which goes hand in hand with the factor powerful, the relationship between hearing dimensions and calculated psychoacoustic descriptors is not one to one. The psychoacoustic descriptors can be more easily assigned to single attributes which describe peculiar properties of certain sounds. The calculation procedures for roughness and fluctuation strength have to be improved to account for the respective attributes on environmental sounds.

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