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Perceptual assessment of water sounds for road traffic noise masking

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Water generated sounds are very popular in the context of soundscape design, due to their inherent positive quality and sound masking properties. This paper examines the perceptual assessment of water sounds in the presence of road traffic noise through the use of auditory experiments. The water sounds used in the experiments were generated by waterfalls, streams, cascades and fountains, with most of the sounds obtained from laboratory tests run under controlled conditions. This ensured an accurate and reliable analysis of the water generated sounds, as well as obtaining a wide range of sounds by varying several designs factors. The results obtained from the auditory experiments include the preferred sound pressure levels of a variety of water sounds against road traffic noise, as well as the preferred water sounds used for masking road traffic noise. All preferences were rated in terms of relaxation.

1 Introduction

The acoustic use of water features is increasingly being considered in the built environment due to the inherent positive qualities of water sounds [1] and due to their ability to mask noise. Following from the extensive acoustic analysis made on water sounds tested in the laboratory [2], this paper presents a perceptual assessment of water sounds for road traffic noise masking. Although the analysis given in this paper is limited to outdoor environments, the water sounds examined are representative of small to medium sized water features which can be installed in both outdoor and indoor spaces such as gardens, parks, hotels' lobbies, offices and restaurants.

The paper starts by discussing the background to the research, followed by a description of the methodology used for tests, a presentation and analysis of results, and conclusions about the main findings of the study.

2 Background

Theoretical details about the mechanisms involved in the generation of water sounds have been discussed in [2] and can be found in [3,4].

The analysis of water generated sounds finds its place in soundscape research, where both physical characteristics and mental perception of the aural and visual environment are typically examined [5]. Most soundscape studies are qualitative by nature and for the case of water sounds, their assessment is often influenced by multiple factors which make it impossible to analyse and understand water sounds in isolation. Some studies have used methods in which water generated sounds could be controlled and analysed in isolation [2,6,7]. These studies are particularly relevant to the research presented here, and are therefore reviewed below in some detail.

The extensive acoustic analysis carried out by Galbrun and Ali [2] has examined the effects of design factors (flow rate, waterfall's edge design, waterfall's width, height of falling water and impact materials) on the acoustics of water sounds generated by small to medium sized water features. The study also compared water sounds with traffic noise, results showing that most water sounds do not generate high sound pressure levels at low frequencies, and are therefore unable to effectively mask traffic noise dominated by low frequencies, as previously suggested by Watt et al. [6]. This is true for most water features, with the exception of waterfalls with large flow rates which can generate high sound pressure levels at low frequencies [2]. The results obtained by Galbrun and Ali [2] also indicated that water tends to be the impact material producing more mid and low frequencies, because of the large vibrating bubbles generated in it.

Listening tests carried out by Watt et al. [6] indicated that improvements in tranquillity could be obtained even for low levels of masking, suggesting that the distracting effect of natural sounds is chiefly responsible for the perceived improvements in tranquillity, and that high levels of masking might not be required to achieve tranquillity.

Jeon et al. [7] carried out qualitative perceptual assessment of urban soundscapes using listening tests, and found that water sounds were the best sounds to use for enhancing the urban soundscape. Furthermore, they found that the water sounds should be similar or not less than 3 dB below the urban noise level, which again indicates that water sounds do not need to mask traffic noise completely to achieve high levels of preference.

This experiment has been replicated here for a variety of water sounds, and results are presented in section 4. An analysis of preferred water sound types, which expands from the previous studies discussed above, is also presented in section 4.

3 Methodology

This section describes the test structures and procedures used to generate water sounds, as well as the methods used for the perceptual assessment of preferred sound pressure levels and preferred water sounds for masking road traffic noise.

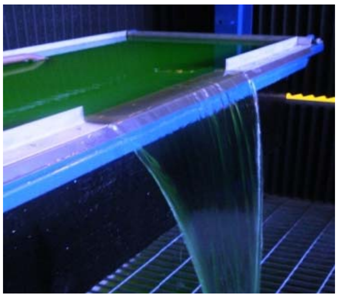
3.1 Water features testing

A variety of waterfalls, fountains and cascades were constructed in the laboratory. This allowed testing different designs and measuring physical parameters (e.g. spectrum and sound pressure level) as well as psychoacoustical parameters (e.g. loudness, sharpness and roughness) under controlled conditions.

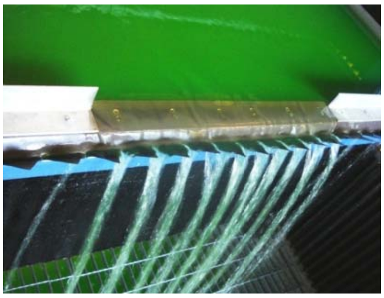
The structure built consisted of a basin encased in the floor and into which water falls, and a tank 1.5m long x 0.5m wide x 0.5m high fixed at a higher level. Two submersible pumps were fixed in the basin and used to circulate water to the upper tank (variable flow rate of up to 150 litres per minute); the tank was attached to a frame which allowed it to reach a maximum height of 2.5m above the floor level.

Measurements were carried out at a distance of 0.5m from the centre section of the basin (impact area of falling water) and 1m above floor level. This receiver position was chosen for its dominant direct field, and absorption panels were also installed around the structure to minimise sound reflections from adjacent surfaces.

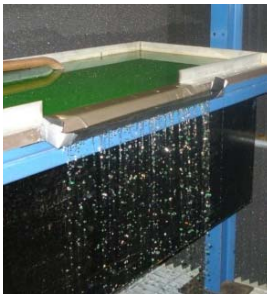
Acoustic parameters were measured using an integrating sound level meter Brüel and Kjaer Type 2250, with a data averaging period of 20 seconds. Audio recordings were also carried out with a digital sound recorder (Zoom H4n)



(a) Plain edge waterfall



(b) Saw edge waterfall



(c) Small holes edge waterfall

(d) Cascade

(e) Fountain (32 jets)

(f) Foam fountain jet

(g) Large and shallow jet

(h) Narrow jet

Figure 1: Examples of water features tested.

connected to Brüel and Kjaer Type 4190 half inch microphones attached to a dummy head. The audio recordings were needed for calculating psychoacoustics parameters through Matlab, as well as in view of listening tests. Further design details about the features tested can be found in [2].

Examples of waterfalls with different edge conditions are shown in Figure 1. Different fountain designs, cascades, as well as upward jets were also tested, and some examples of the configurations examined are given in Figure 1.

Field tests were also carried out to obtain data of water features which could not be built and tested in the laboratory. All the sounds used in the auditory tests presented here were obtained from the laboratory, with the exception of one shallow stream recording which was made in the field (Pentland Hills, Edinburgh, UK). Details of the water sounds used in the listening tests are given in Table 1.

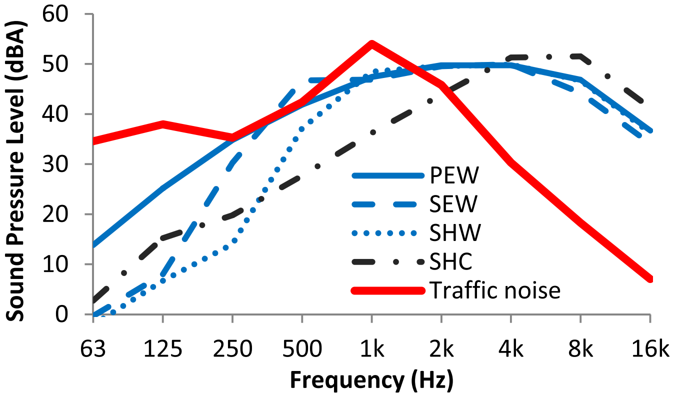
3.2 Perceptual procedures

This section describes the procedures used in the listening tests carried out for the study. Twelve different water sounds have been used in these tests (Table 1). These sounds have been played over road traffic noise recorded in a field located 200m from the centre of a busy motorway (M8 Edinburgh – Glasgow). Figure 2 illustrates the water and traffic noise spectra normalized to 55 dBA (as an indication of the auditory tests' perception), where it can be seen that traffic noise is dominated by low and mid frequencies, whilst water sounds are dominated by mid and high frequencies (detailed analysis of the water sound properties can be found in [2]).

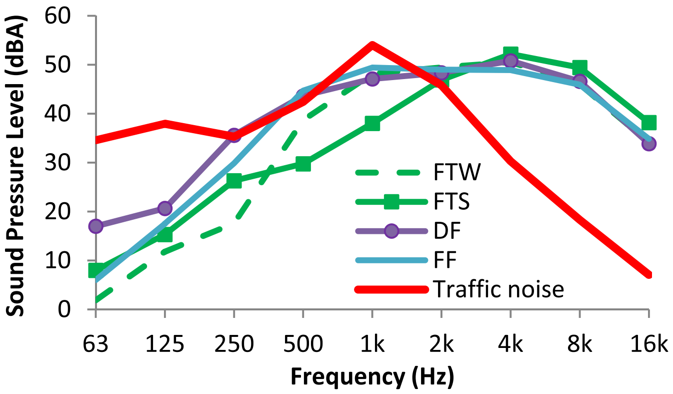
Two types of listening tests have been undertaken. Firstly, a test was carried out to identify the preferred sound pressure level of water sounds over road traffic noise, and

Table 1: Properties of water sounds used in the auditory tests.

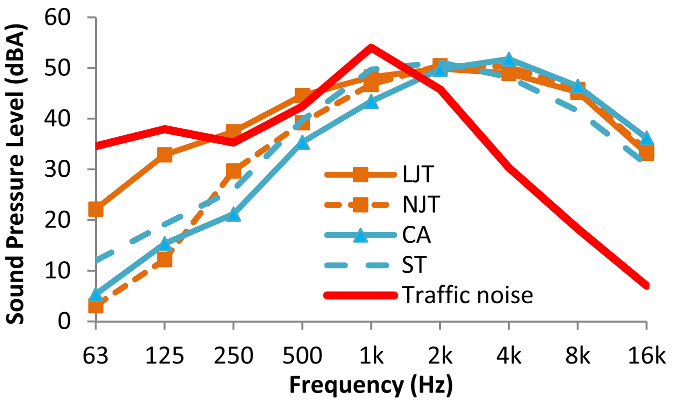
Sound code	Water features type	Impact material	Flow rate (l/min)	Height (m) – Width (m)
PEW	Plain Edge Waterfall	Water	120	1.0 – 1.0
SEW	Saw Edge Waterfall	Water	30	0.5 – 1.0
SHW	Small Holes edge Waterfall	Water	30	0.5 – 1.0
SHC	Small Holes edge Waterfall	Concrete	30	0.5 – 1.0
FTW	Fountain (32 jets)	Water	30	-
FTS	Fountain (32 jets)	Stones (pebbles)	30	-
DF	Dome fountain	Water	30	-
FF	Foam fountain	Stones (pebbles) & boulders	30	-
LJT	Large jet (25mm nozzle)	Water	15	-
NJT	Narrow jet (10mm nozzle)	Water	15	-
CA	Cascade (4 steps)	Stones (pebbles)	15	-
ST	Stream	Stones and water	Low (not meas.)	-



(a) Waterfalls.



(b) Fountains.



(c) Jets, cascade and stream.

Figure 2: Normalised spectra of road traffic noise and water sounds used in the auditory tests.

secondly, another test was carried out to identify the preferred water sounds in the presence of road traffic noise. Details of the methods used in these two tests are given below.

3.2.1 Preferred sound pressure levels

The procedure used was the same as the one developed by Jeon et al. [7], with a constant traffic noise level played at 55 dBA, and with water sounds played at either 49, 52, 55, 58 or 61 dBA (i.e. -6 dB, -3 dB, 0 dB, +3 dB or +6dB relative to the road traffic noise level). The test was carried out for six different water sounds: SHW, PEW, CA, FTW, FF and LJT (refer to Table 1 for details).

The listening test included ten paired comparisons per water sound, for a total of sixty paired comparisons. Furthermore, ten comparisons were repeated in order to examine the consistency of subjects. In view of statistical validity, the sequence of paired comparisons was randomised, so that sounds were presented in a different order for each subject.

Thirty four subjects with normal hearing participated in the test (fourteen males and fourteen females), all of which were either students or researchers working at Heriot-Watt University (average age of 26.6). The test was carried out in the anechoic chamber of Heriot-Watt University, a highly insulated space with a background noise level of around 17 dBA. Instructions were initially given to the subjects, who had to imagine that they were relaxing in a balcony or garden where they could hear road traffic noise from a nearby motorway as well as a water feature (same as [6]). Binaural signals were played back through headphones (Beyerdynamic DT 150), where each paired comparison consisted of seven seconds of sound 1, one second of silence, seven seconds of sound 2, and three seconds of silence before the next pair was played. For each comparison, subjects had to select the sound which they found more peaceful and relaxing.

Five paired comparisons were initially played for familiarisation with the methods. Once the subject was clear about the procedure, the actual test could be started. This consisted of ten paired comparisons played in an automated sequence (slide presentation), after which the subject was free to take a break before continuing with the following ten pairs, in order to maintain a high concentration level. The test lasted around 30 minutes per subject, including instructions and breaks.

3.2.2 Preferred water sounds

In this test, paired comparisons were made between twelve water sounds (Table 1) played over road traffic noise. All the water sound pressure levels and traffic noise levels were played at 55 dBA. A total of 76 paired comparisons were carried out per subject, including the ten repetitions made for the analysis of consistency. The sequence of paired comparisons was randomised for all tests.

Similarly to the test made for preferred sound pressure levels, thirty four subjects with normal hearing participated in the test (fourteen males and fourteen females), all of which were either students or researchers (different sample than the previous one, with an average age of 28.6). The method used for instructing subjects and presenting the paired comparisons was identical to what has been described in section 3.2.1. The test lasted around 35 minutes per subject, including instructions and breaks.

4 Results

4.1.1 Preferred sound pressure levels

Twenty nine students (fifteen males and fourteen females) of average age 26.3 passed the consistency test and were retained for the analysis of results (repeatability of at least 6 out of 10).

Results are shown in Figure 3 with normalised preferences given on the vertical axis, where positive values indicate sounds selected in most of the comparisons (i.e. sounds which are most liked), and negative values indicate

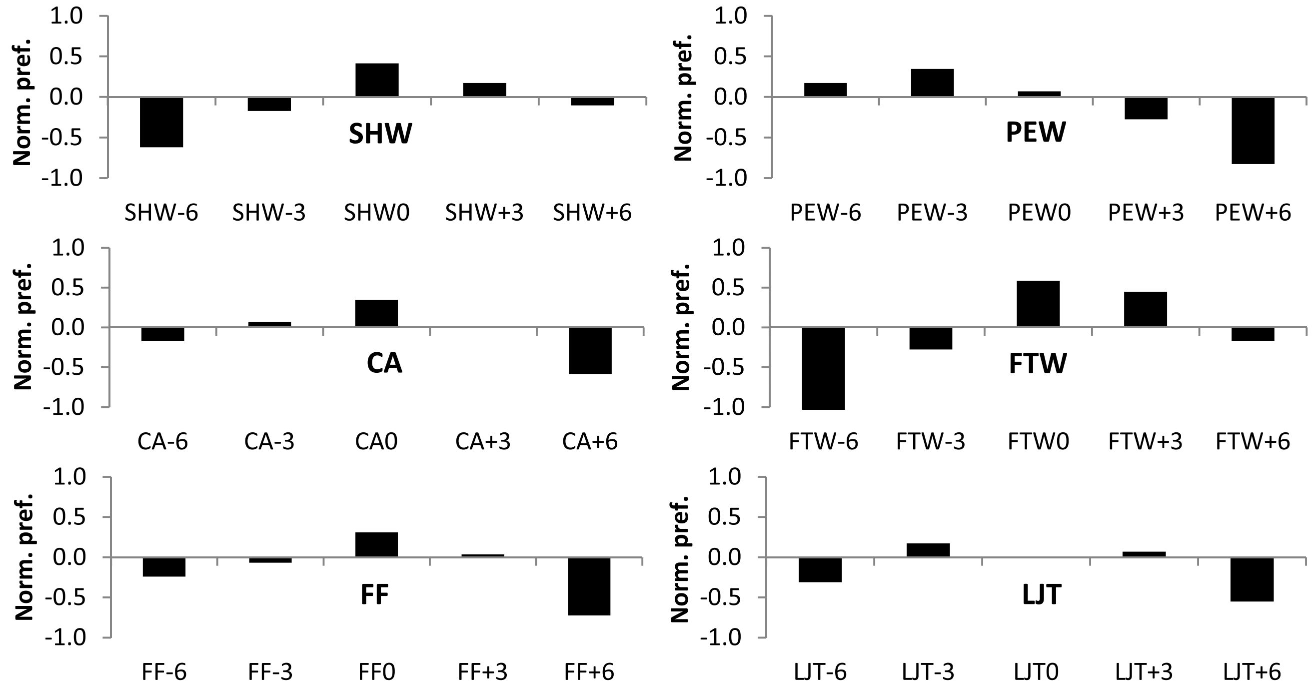


Figure 3: Preferred water sound pressure levels.

sounds less liked. In the figure it can be seen that, for the four sounds SHW, CA, FTW and FF, the preferred water sound pressure level was the same as the road traffic noise level (0 dB difference, i.e. 55 dBA level), whilst for the remaining two sounds PEW and LJT, the preferred level was 3 dB below road traffic noise (i.e. 52 dBA level). These results confirm the findings of Jeon et al. [7] according to which the water sounds should be similar or not less than 3 dB below the urban noise level.

A statistical analysis of the results obtained also indicated no statistically significant difference in responses between the different gender, age and cultural groups (Mann-Whitney test) [8].

4.1.2 Preferred water sounds

Thirty one students (fifteen males and sixteen females) of average age 27.8 passed the consistency test (repeatability of at least 6 out of 10) and were retained for the analysis of results, which are given in Figure 4 and Table 2. These indicate that the preferred water sounds are the natural stream ST, the fountain made of 32 jets FTW, the large jet with a low flow rate and shallow distribution of water LJT, and the cascade with four steps CA. In contrast, the least liked sounds are the waterfalls with small holes SHW and SHC (rain type of sound), the waterfall with a plain edge and a very large flow rate (maybe evocative of sewage systems), and the single jet with a narrow nozzle (water tap type of sound, which may again be evocative of sewage systems).

As for the preferred sound pressure level test, a statistical analysis of the results obtained indicated no statistically significant difference in responses between the different gender, age and cultural groups (Mann-Whitney test) [8].

It should however be noted that concordance analysis indicated a statistically low agreement between subjects (Kendall's coefficient of concordance $W < 0.4$) [8]. This suggests that different results could be obtained if the test was to be repeated with different subjects. Latent class analysis [9] actually shows that the subjects' sample can be divided into two clusters in terms of rating agreement (Cluster 1: 17 subjects; Cluster 2: 14 subjects). The results obtained for the different clusters are given in Table 2, where it can be seen that the ranking variations are actually not significant, as the ranking positions of sounds do not vary markedly. This justifies the analysis based on three different ranking groups shown in Table 3, where group 1-4 includes sounds ST, FTW, LJT and CA, group 5-8 includes FF, SEW, DF and FTS, and group 9-12 includes SHW, SHC, PEW and NJT. These groups suggest that the preferred water sounds have larger temporal variations in levels (higher $L_{AFmax} - L_{AFmin}$), lower sharpness (i.e. lower high frequency content), lower roughness, and a higher maximum pitch strength. Results also suggest that fountain sounds tend to be preferred over waterfall sounds, and that water is the preferred impact material, as hard materials increase the high frequency content and sharpness of the sound, hence reducing its sound quality.

Overall, gentle types of sounds with low frequency content and low flow rates, which are typical of natural streams, represent most of the preferred water sounds (ST, LJT, CA). Finally, it can be noted that the shallow stream sound (ST) is by far the preferred water sound, and it is interesting to point out that this was the only field sound used in these tests (temporally variable type of sound with a strong spatial quality clearly reflected in the left and right channels of the binaural recording, as the sound was measured at the junction of two streams).

5 Conclusions

Auditory experiments have been carried out to identify the preferred sound pressure levels of a variety of water sounds against road traffic noise, as well as the preferred water sounds to be used for masking road traffic noise. The results obtained for the preferred sound pressure level confirm the findings of Jeon et al. [7], suggesting that the water sounds should be similar or not less than 3 dB below

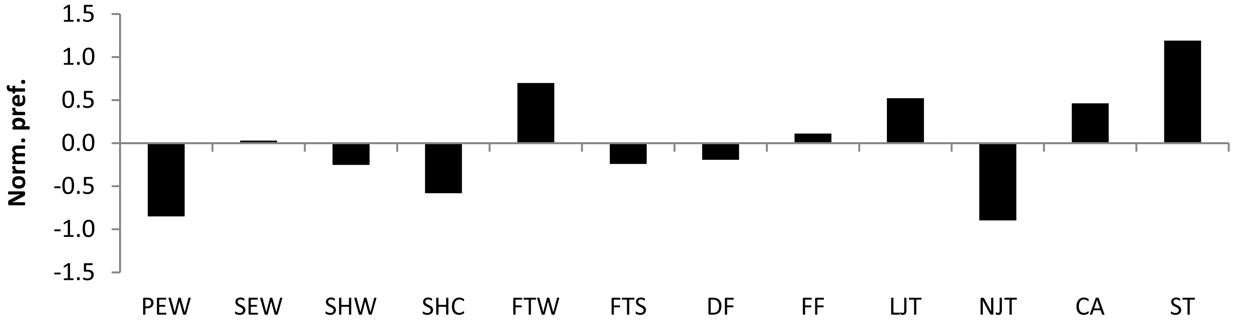


Figure 4: Preferred water sounds.

Table 2: Ranking of preferred water sounds.

Sound ranking	**Clusters 1+2**		**Cluster 1**		**Cluster 2**	
	Sound code	Norm. pref.	Sound code	Norm. pref.	Sound code	Norm. pref.
1	ST	1.19	ST	1.12	ST	1.27
2	FTW	0.70	LJT	0.84	FTW	0.99
3	LJT	0.52	FTW	0.46	CA	0.73
4	CA	0.46	CA	0.25	LJT	0.13
5	FF	0.11	FF	0.20	SEW	0.13
6	SEW	0.03	DF	-0.03	FF	0.00
7	DF	-0.19	SEW	-0.05	SHW	-0.08
8	FTS	-0.24	FTS	-0.12	DF	-0.39
9	SHW	-0.25	SHW	-0.40	FTS	-0.39
10	SHC	-0.58	SHC	-0.50	PEW	-0.60
11	PEW	-0.85	NJT	-0.72	SHC	-0.68
12	NJT	-0.90	PEW	-1.06	NJT	-1.12

Table 3: Ranking groups with corresponding acoustic and psychoacoustic parameters.

Sound ranking groups	**Median L_{AFmax} - L_{AFmin} (dB)**	**Median Sharpness (acums)**	**Minimum Roughness (aspers)**	**Maximum Roughness (aspers)**	**Maximum Pitch Strength**
1-4	6.6	2.02	0.02	1.01	0.36
5-8	4.6	2.06	0.05	1.31	0.32
9-12	3.7	2.26	0.07	1.66	0.27

the road traffic noise level.

The auditory tests made on different water sounds indicate that gentle types of sounds with low frequency content and low flow rates tend to be preferred (e.g. natural streams), that fountain sounds tend to be preferred over waterfall sounds, and that water is the preferred impact material, as opposed to hard materials. Finally, it should be noted that the analysis provided here is limited due to the paper's length restriction, but a more detailed analysis of results will be provided at the conference presentation.

References

[1] J. Kang, *Urban Sound Environment*, Taylor and Francis, New York (2007)

[2] L. Galbrun, T.T. Ali, "Acoustic design of water features for the built environment", *Proceedings of the Institute of Acoustics*, 33(4), 112-119, Acoustics 2011, Glasgow, 14-15 September (2011)

[3] G.J. Franz, "Splashes as sources of noise in liquids", *J. Sound Vib.* 31, 1080-1096 (1959)

[4] T.G. Leighton, *The Acoustic Bubble*, Academic Press, London (1994)

[5] R.M. Schafer, *Our Sonic Environment and the Soundscape: The Tuning of the World*, Destiny books, Vermont (1994)

[6] G. Watts, R. Pheasant, K. Horoshenkov, L. Ragonesi, "Measurement and subjective assessment of water generated sounds", *Acta Acust. united with Acust.* 95, 1032-1039 (2009)

[7] J.Y. Jeon, P.J. Lee, J. You, J. Kang, "Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds", *J. Acoust. Soc. Am.* 127(3), 1357-1366 (2010)

[8] A. Field, *Discovering Statistics using SPSS*, 2nd edition, Sage, London (2005)

[9] J.A. Hagenaars, A.L. McCutcheon, *Applied Latent Class Analysis*, Cambridge University Press, Cambridge (2002)