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Auditory adaptation to loudspeaker and listening room acoustics

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ABSTRACT

Timbral qualities of loudspeakers and rooms are often compared in listening tests involving short listening periods. Outside the laboratory, listening occurs over a longer time course. In a study by Olive *et al*. (1995) smaller timbral differences between loudspeakers and between rooms were reported when comparisons were made over shorter versus longer time periods. This is a form of timbral adaptation, a decrease in sensitivity to timbre over time. The current study confirms this adaptation and establishes that it is not due to response bias but may be due to timbral memory, specific mechanisms compensating for transmission channel acoustics, or attentional factors. Modifications to listening tests may be required where tests need to be representative of listening outside of the laboratory.

1. INTRODUCTION

Timbre is largely determined by the steady state spectrum of a sound source. This spectrum is coloured by the frequency response of transmission channels through which the sound passes (e.g. loudspeakers, rooms, telephone lines). Listening tests have shown that loudspeaker frequency response causes differences in sound timbre and affects loudspeaker preference. Tests also show that the listening room affects timbre, with ratings changing between rooms [1]-[3]. This occurs via the incorporation of the spectral characteristics of room reflections into the spectrum of the direct sound [4]-[6].

Compared to the changing spectra of sounds passing through the transmission channel, the channel spectrum is heard continuously for longer (e.g. unchanging loudspeaker resonances) or with increased repetitions (e.g. room reflections). Adaptation, a decrease in sensitivity to a stimulus with time, might diminish the effect of loudspeaker and room spectrum on perception. This adaptation can occur via a number of mechanisms. Adaptation can result from continuous listening to a stimulus: the loudness of a pure tone may reduce over a period of seconds and minutes, due to neural fatigue or cognitive bias [7]-[9]. Adaptation has also been demonstrated with repeated listening to a stimulus: the influence of a reflection on the perceived location of a sound is shown to decrease with multiple repetitions.

Higher level processes, such as learning, may be involved as well as lower level neural processes [10]-[11]. Timbral differences between stimuli may also be decreased where there is time between stimulus presentations because of reduced sensory memory for timbral detail [12]-[14].

Specific mechanisms that are designed to compensate for the spectrum of transmission channels have also been reported. The enhancement effect [15]-[16] and the spectral compensation effect [17]-[18] are thought to demonstrate mechanisms which reduce the perceptual effects of an unchanging spectrum (i.e. that of a static transmission channel), compared to that of a changing spectrum (e.g. speech heard within that channel). These mechanisms result in the enhancement of spectral changes when changes occur close by in time. The enhancement effect is thought to be due to neural adaptation in response to continuous stimulation over a few hundred milliseconds [15],[19]. The spectral compensation effect has been found to persist with contralateral presentation which indicates that a central process is behind this effect. A cognitive mechanism may be involved in the calculation of, and subtraction of the long term average spectrum. Stimulus specific neural adaptation has also been put forward [17]-[18].

A study by Olive *et al*. [2] indicated that adaptation affects loudspeaker and room timbre. In this study listeners rated, for timbral preference, musical program items played through different loudspeakers in different rooms. Statistically significant differences in preference between loudspeakers and between rooms were observed when a 'direct' comparison method was used. This method allowed listeners to compare binaural recordings of loudspeakers and rooms by switching instantaneously between them. However, no significant differences between the same stimuli were found when compared using an 'indirect' comparison method which involved stimuli being presented continuously for longer, time gaps between presentations and less attention directed towards stimulus differences.

Olive *et al.* suggested that adaptation to timbre with indirect comparisons might be due to time gaps between stimulus presentations and auditory memory. Toole [3],[20] and Olive and Martens [21] suggested that spectral compensation effects may be behind the results. Time between presentations may have prevented the enhancement of differences between sounds with indirect comparisons. Olive and Martens also stated that time spent listening continuously within a room (or to a loudspeaker) might explain adaptation. Stimuli were presented for longer with the indirect comparison method and mechanisms similar to those behind loudness adaptation might have caused adaptation in this experiment.

Another explanation for the results in Olive *et al.* is that they are due to response bias rather than adaptation [22]. The study design drew listeners' attention to timbral changes when direct comparisons were made but not when indirect comparisons were made. This might have biased listeners to preferentially report differences between directly presented stimuli.

The study by Olive *et al*. highlights a potential problem with audio listening tests. The direct comparison method, where stimuli are compared side by side and heard for a short time, is similar to the methods used to make comparisons in many standard listening tests, including MUSHRA, 2AFC and ABX tests (see [23] for an overview). The indirect comparison method is more similar to real-world listening, where judgments of timbral fidelity or preference are often made over longer time courses. If adaptation occurs, the results of some listening tests might be unrepresentative of real-world listening.

Despite the potential importance of Olive *et al*'s findings, only one study has attempted to replicate and extend this research. This study found no adaptation when multichannel loudspeakers were used [21]. Further work is therefore needed to confirm that adaptation to loudspeaker and room timbre occurs. Research into the mechanisms behind this adaptation is also needed to increase understanding of the adaptation process and establish appropriate adjustments to listening tests.

This paper documents two experiments in this area. Experiment 1 aimed to confirm the effect of comparison method in Olive *et al*. by replicating their experiment. Experiment 2 aimed to explain the processes behind any adaptation seen in experiment 1.

	Loudspeaker 1	Loudspeaker 2	Loudspeaker 3
Type	Double balanced passive radiator. Floor standing. Tweeter elevation 100 cm	Active near-field monitor. Mounted on stand. Tweeter elevation 130 cm	2-way Passive bookshelf speaker. Mounted on stand. Tweeter elevation 130 cm
Bass driver	125 W, Class D, ICE power 102 mm/4" concave diaphragm - 1 forward facing active driver and 2 90º facing passive radiator drivers	150 W RMS 200 mm	165 mm (6.5")
Tweeter	125 W, Class D, ICE power 19mm / (3/4)" coated fabric dome with acoustic lens to improve high frequency directivity	60 W RMS 25 mm with centre plug waveguide	25 mm (1")
Frequency response	50 - 23,000 Hz (±3 dB)	60 - 40,000 Hz (±3 dB)	60 - 20,000 Hz (±3 dB)

Table 1: Loudspeaker characteristics

2. EXPERIMENT 1

To confirm the effect of indirect-*vs*-direct comparison method, Olive *et al*.'s [2] experiment was repeated but with different loudspeakers and rooms, and a speech program item. The hypothesis that longer continuous listening explains the effect was also tested.

2.1. Loudspeakers & Rooms

3 loudspeakers were chosen which, like in Olive *et al*., [2] were representative of high-quality consumer loudspeakers. Table 1 details the loudspeaker characteristics. Mono reproduction was chosen because previous experiments have used this to limit preference decisions to timbral, rather than spatial, attributes [1]-[2].

3 rooms were chosen to cover a similar range of rooms as Olive *et al*. Room 1 was an office measuring 4.7 × 4.1 × 2.5 m (*l* × w x *h*). RT60 averaged over 500 Hz–1 kHz was 0.31 s. Wooden desks were positioned against walls and there were no soft furnishings. Room 2 was a studio control room measuring 6.4 × 5.6 × 2.6 m. RT60 was 0.18 s. Room 3 was an ITU-R BS.1116 listening room measuring 7.4 × 5.3 × 2.5 m. RT60, 0.25 s. The room had carpeted floor, lay-in-grid tile absorbent ceiling, and full range acoustic absorber boxes on the walls.

2.2. Binaural Stimuli

Binaural recordings of each loudspeaker in each room, played over headphones, were used to allow for blind presentation and instantaneous switching between loudspeakers and rooms. It is well established that binaural recordings offer an experience that is perceptually similar to listening in-situ [24][2]. Recordings were made with a Cortex Instruments MKII Head And Torso Simulator (HATS) fitted with $^1/_2$'' MK231 condenser capsule microphones, a diffuse field filter and a high pass filter set at 0.7 Hz.

Placement followed Olive *et al.* [2]: the loudspeaker was positioned 1.1 m from the back wall, facing the HATS; the HATS was positioned 2.9 m directly in front of the loudspeaker. Tweeter height was raised 1.3 m above ground for loudspeakers 2 and 3 and 1.0 m for loudspeaker 1. The ears of the HATS were elevated 1.3 m to the approximate position of a seated listener.

Left- and right-ear impulse responses (IRs) were captured for each loudspeaker/room combination using a 20 Hz–20,000 Hz, 15 s exponential sine sweep. Each stereo IR was then convolved with the programme item to produce a binaural stimulus. The program item was monophonic anechoic male speech (track 5, Bang and Olufsen 1992). Stimuli were level-balanced using A-weighted LEQ.

2.3. User Interface & Rating scale

The computer-based experiment interface was page based. Each page presented 3 stimuli (A, B, C), each triggered by clicking the appropriate button and each with an associated rating slider. Listeners could replay the stimuli on a page in any order, for as long as desired, and as many times as desired. Stimuli were randomised on each page.

The rating scale from Olive *et al*. [2] was used: this was a scale of 1–100 with descriptors displayed at: 10 points, 'really dislike'; 30 points, 'moderately dislike'; 50 points, 'neither like or dislike'; 70 points, 'moderately like'; and 90 points, 'really like'.

2.4. Listeners

16 students of the Institute of Sound Recording, University of Surrey took part. All students had undergone technical ear training as part of their studies and reported no hearing deficiencies.

2.5. Instructions

Listeners were asked to rate each stimulus for preference. They were told to use at least a 20-point difference between ratings to mark a strong difference in preference, 10–20 points to mark a moderate difference and 5–10 points to mark a small difference. To prevent possible expectation bias, listeners were not told the nature of the stimuli.

		Test Phase (at least 24h separating conditions)			
		Loudspeaker (LS) condition		Room (R) Condition	
Page	Block	Loudspeaker assignment to ABC	Room	Room assignment to ABC	LS
1	1	LS1,LS2,LS3	1	R1,R3,R2	1
2		LS3,LS1,LS1		R1,R2,R3	
3		LS3,LS2,LS1		R1,R3,R2	
4		LS2,LS1,LS3		R2,R1,R3	
5		LS1,LS2,LS3		R2,R1,R3	
6		LS3,LS1,LS2		R3,R2,R1	
7		LS3,LS1,LS2		R3,R1,R3	
8		LS2,LS1,LS3		R1,R2,R3	
9		LS1,LS2,LS3		R2,R3,R1	
Break (10 minutes)					
Pages 10-18	2	As for pages 1–9	2	As for pages 1–9	2
Break (10 minutes)					
Pages 19-27	3	As for pages 1–9	3	As for pages 1–9	3

Table 2: Test phase procedure for the loudspeaker condition and the room condition, for a single participant.

3. TEST PROCEDURE

Stimuli were reproduced through Sennheiser HD-650 headphones. No headphone equalization was applied. Testing was carried out in an ITU-R BS.1116 listening room.

3.1.1. Familiarisation phase

Prior to the test, all loudspeaker and room combinations were presented so that listeners could familiarise themselves with the range of stimuli, establish the attributes upon which they would be basing their preference, and practise using the rating scale.

3.1.2. Test phases

Two conditions were tested and the test phase for each condition followed a blocked design (Table 2). In the *loudspeaker condition*, in each block listeners compared all 3 loudspeakers against each other *directly*, in one particular room. Within each block, each 3-stimulus comparison was repeated 9 times (on 9 separate interface pages). Repeated ratings allowed extended listening within the same room. There was a 10 minute break between blocks. Each block used a different room (randomly selected). A measurement of room preference was obtained by examining preference differences across blocks. Rooms were therefore compared only *indirectly*.

In the *room condition*, in each block listeners compared all 3 rooms against each other directly, using one particular loudspeaker, and each block used a different loudspeaker; thus loudspeakers were compared indirectly.

Listeners were randomly assigned to complete the loudspeaker or the room condition first. They returned to complete the 2nd condition after a period of 24hrs or longer.

3.2. Results

Data were checked for normality and the reliability of listeners assessed. Listeners were inconsistent when making repeated ratings but variation was similar for all participants and appears to represent the difficulty of the task. Most listeners reported difficulty in consistently rating timbral preference.

Figure 1 shows the ratings for the loudspeaker condition (loudspeakers compared directly, rooms indirectly) and the room condition (rooms compared directly, loudspeakers indirectly). As is expected by the adaptation hypothesis, a contraction of ratings can be seen with the indirect comparison method.

Separate repeated measures (RM) ANOVA analysis was conducted for each condition. A significant effect of loudspeakers and rooms was found in both conditions. Differences between loudspeakers were larger when compared directly ($F(2,286)=91.195$ $p<.001$) than when compared indirectly ($F=20.663$ $p<.001$). Differences between rooms were larger when compared directly ($F=405.712$ $p<.001$) than when compared indirectly ($F=18.008$ $p<.001$). This confirms the results of Olive *et al*. of reduced main effects with indirect comparisons. Further, it was evident that this reduction was not due to increased error with indirect comparisons, but a decreased effect size, as error measurements were similar or smaller when comparisons were made indirectly. This contraction of effect size is expected by the adaptation hypothesis.

A single RMANOVA analysis was conducted to examine main effect-by-condition interactions. The loudspeaker-by-condition interaction was significant ($F(2,286) = 58.989$ $p<.001$) and the room-by-condition interaction was significant ($F=187.216$ $p<.001$). This confirms that the reduction in main effect with indirect comparisons is statistically reliable.

To test the hypothesis that the effect of comparison method is due to longer continuous presentation [21], the analysis conducted above was repeated using only data from the 1st 3 experiment pages of each block and, separately, data from the last 3 pages, of each block. The time spent on each experiment page showed that listeners had experienced the indirect factor continuously for 25s–2 minutes when rating the first 3 experiment pages, and for 3–4 minutes when rating the last 3 experiment pages. Differences between indirectly compared stimuli were not significantly smaller with longer time spent listening. Therefore the effect of comparison method cannot be attributed to adaptation occurring with the region of 25s–4 minutes.

4. EXPERIMENT 2

In experiment 2 the processes behind the effect of comparison method were examined further. It was hypothesized that the effect is to do with: (a) the break phases between stimulus presentations causing reduced timbral memory [2], and a tendency to report differences as smaller where memory is reduced; and/or (b) break phases preventing specific mechanisms, such as the enhancement and spectral compensation effects, from working to enhance differences between stimuli [3][20]-[21]. In experiment 2 the effect of removing break phases was tested (0 minute break condition). Break phases were removed for all participants and results compared to those obtained in experiment 1 (10 minute break condition).

The effect of comparison method may also be due to (c) the instructions and task format resulting in reduced attention being drawn to indirectly presented stimuli. Listeners were explicitly instructed to compare differences between stimuli on a single page (the direct factor), but were not told that changes across blocks occur and that these should also be reflected in ratings. This may have caused response bias. Listeners might have thought that the purpose of the task was to measure differences occurring on each page and that any changes across pages were irrelevant. They may have therefore intentionally recalibrated their rating scales with each new page to use 50 points as a mid-point for preference [22]. This would result in differences across blocks being removed from ratings. Even if this response bias did not occur it is possible that differences across blocks were less salient because of reduced attention being drawn to them. Instructions to listen for changes across the test and report these in ratings would be expected to reduce the effect of comparison method if response bias, or attention, is behind the effect.

In experiment 2 half the listeners were given specific instructions to make 'global' ratings reflecting differences in stimuli across the test as well as on a single page (instruction condition). Further explanation of this request was given if needed. The remaining listeners were given the same instructions as in experiment 1 (no instruction condition).

4.1. Listeners, materials and procedure

16 listeners who had not participated in experiment 1 were selected using the same criteria as in experiment 1. All materials and procedure were the same as experiment 1 except for the removal of break phases between blocks, and additional instructions to make global ratings for the instruction group (n=8).

4.2. Results

The results for the no instruction group were analyzed to determine if removing break phases reduced the effect of comparison method compared to experiment 1. Figure 2 shows that an effect of comparison method still occurred when break phases where removed, with smaller timbral differences reported with indirect comparisons. It can also be seen that the effect of comparison method is slightly smaller in this experiment compared with experiment 1. This mainly occurs for the room factor. Separate RMANOVA analyses for the loudspeaker and the room condition showed a significant effect of loudspeaker in the loudspeaker condition ($F(2,142)=39.303$ $p<.001$) but not in the room condition ($F=1.391$ $p=.252$). The effect of room was significant in the room condition ($F=330.830$ $p<.001$) and in the loudspeaker condition ($F=62.258$ $p<.001$). The loudspeaker-by-condition interaction ($F(2,142)=25.837$ $p<.001$) and the room-by-condition interaction ($F=46,417$ $p<.001$) showed a significant effect of comparison method for both factors.

To test whether the effect of comparison method in experiment 2 was significantly reduced compared to experiment 1 a single mixed ANOVA was conducted. The loudspeaker-by-condition-by-experiment interaction was significant but small ($F(2,142)=6.430$ $p=.002$ partial eta squared=.021). The room-by-condition-by-experiment interaction was larger ($F=16.497$ $p=.000$ partial eta squared =.055). These results confirm the reduced effect of comparison method seen in experiment 2 compared to experiment 1. The magnitude of the effect of comparison method between experiments can be compared by examining preference ratings. In experiment 1 the difference between the most preferred loudspeaker and the least preferred loudspeaker (averaged across rooms) was 13 preference points in the loudspeaker condition compared to 3 points in the room condition (a difference of 10 points with comparison method). In experiment 2 the difference between the most preferred loudspeaker and the least preferred loudspeaker was 9 points in the loudspeaker condition compared to 1 point in the room condition (a difference of 7 points with comparison method). This shows a negligible (3 points) reduction in the effect of comparison method in experiment 2, according to rating scale values. Likewise in experiment 1 the difference between the most preferred room and the least preferred room (averaged across loudspeakers) was 36 points in the room condition, compared with 7 points in the loudspeaker condition (a difference of 29 points with comparison method). In experiment 2 this difference was 39 points in the room condition and 19 points in the loudspeaker condition, a 20-point difference in preference with comparison method. The reduction in effect of comparison method is small (9 points) according the preference rating values.

These results suggest that break phases between stimulus presentations were partly responsible for the effect of comparison method in experiment 1 and have a greater effect for the room factor. For the loudspeaker factor the reduced effect of comparison method in experiment 2 is not perceptually important. Further it occurred mainly because of a decrease in perceived variation in loudspeakers when compared directly in experiment 2, rather than an increase in perceived variation with indirect comparisons. This is not expected by the adaptation hypothesis, so break phases cannot be said to explain adaptation to loudspeakers. For the room factor, effects were small but in the expected direction: removing breaks caused larger perceived differences in rooms with the indirect comparison method. For this factor it can be concluded that break phases are partly behind the effect of comparison method. However, a considerable effect of comparison remained after the removal of break phases. Therefore other factors must also play a role in the adaptation to rooms seen in these experiments.

The results with instructions to make global ratings across the experiment were compared with the *no instructions* condition. An effect of comparison method was observed with and without instructions. The effect of instructions on the effect of comparison method was almost non-significant for the loudspeaker factor (loudspeaker-by-condition-by-instructions interaction $F(2,142)=3.138$ $p=.045$ partial eta squared=.022). The effect of instructions was small but significant for the room factor (room-by-condition-by-instructions interaction $F=7.549$ $p=.001$ partial eta squared=.050). However, for both factors the effect of comparison method reduced with instructions mainly because differences became smaller when compared directly, rather than because differences became larger when stimuli were compared indirectly.

The results show that encouraging listeners to listen for changes across the whole condition (i.e changes due to the indirect factor) was not effective in increasing listeners' tendency to report differences between indirectly compared stimuli. Instead, these instructions appeared to result in listeners having a slight tendency to be more conservative in reporting differences for the directly compared stimuli, at least for the room factor. This is not expected by the adaptation hypothesis. Instructions do not therefore explain adaptation seen in these experiments.

5. DISCUSSION

The results of Olive *et al*., [2] have been confirmed: timbral differences between loudspeakers and between rooms are larger when comparisons are made using a direct comparison method (involving side-by-side stimulus presentations and short listening periods) than when using an indirect method (involving time gaps between listening, longer listening periods and less attention directed to timbral differences). This effect of comparison method indicates adaptation, a decrease in sensitivity, to timbre when listening is conducted over longer listening periods. The statistical reliability of adaptation effects were not reported by Olive *et al*. but here results have been shown to be statistically reliable. This work has also extended the reach of Olive *et al*'s results to speech sounds and to other loudspeakers and rooms.

Olive *et al*. found that no significant differences remained between loudspeakers and rooms when the indirect comparison method was used. This shows that that adaptation was complete in their study. Significant differences remained in this study. This is likely to be due to objective differences in loudspeakers and rooms being larger in this experiment, and/or because task or stimuli differences caused a weaker adaptation effect. It is unlikely that the new speech program item is subject to weaker adaptation than the musical items used in *Olive et al.* as evidence for adaptation to transmission channels has been found for speech sounds [6].

The effect of comparison method was partly explained by the break phases between stimulus presentations with indirect comparisons. When rooms were indirectly compared, the removal of break phases resulted in differences between rooms being reported as larger. When loudspeakers were indirectly compared, removing the break phases did not result in larger differences between loudspeakers but there was a slight tendency to rate differences between loudspeakers when directly compared as smaller. Smaller differences for the direct factor might be expected with the removal of time gaps, as listeners might be making room on the rating scale for the, now larger, differences due to the indirect factor. However, as there appears to be no reduction in the effect of comparison method due to loudspeakers being perceived as more different when rated indirectly, the removal of break phases does explain adaptation for the loudspeaker factor.

Adaptation to room timbre may be partly due to sensory memory or spectral compensation mechanisms, both of which result in reduced perceptions of difference with time gaps between stimuli. Further experiments are necessary to determine whether one or both of these factors is behind results. It is not clear why these processes only appear to reduce sensitivity to room timbre and not to loudspeakers. The result may be due to the fact that differences between rooms were more salient to begin with. It is also acknowledged that different mechanisms are likely to be behind adaptation to room spectrum and adaptation to loudspeaker spectrum. Timbral memory and spectral compensation mechanisms might work differently for these different channels.

It should be noted that simply removing the break phase did not make the time between stimulus presentations equal for the directly- and indirectly-compared stimuli. Some indirect comparisons still involved time between stimuli (e.g. the comparison between room 1 and room 3 in table 2). This may have resulted in reduced sensitivity to timbral differences. A comparison of side-by-side presentation *vs* non-side-by-side stimuli was conducted to determine whether, when time gaps between directly and indirectly compared stimuli are equal, smaller differences for indirectly-compared stimuli remain. However, lack of statistical power prevented conclusive analysis. It is expected that future studies will reveal that timbral differences are larger when side-by-side presentations can be made, as both sensory memory and spectral compensation mechanisms can work to enhance differences.

It was predicted that instructions might explain the effect of comparison method. However, instructing listeners to listen for changes across the test did not increase reported differences between indirectly-compared stimuli. Some reduction in the effect of comparison method with instructions was seen but this was due to differences between stimuli being slightly reduced with direct comparisons, rather than increased differences for indirectly compared stimuli being observed. Instructions cannot be said to be behind adaptation. The fact that instructions are not behind this effect means that we can be confident that listeners were not intentionally ignoring changes across the test and recalibrating their preferences scales on each experimental page. The instructions manipulation would have prevented this, yet the effect of comparison method remained strong. It can therefore be concluded that response bias was not behind adaptation seen in in these experiments. It appears that Olive *et al.* used similar instructions and so this result may further show that response bias was not behind their results. However, attention to timbral differences between direct and indirect comparisons remained unequal even with extra instructions and attention should be further tested for its role in the effect of comparison method.

The results in this experiment are contrary to those of Bech [1], who showed that stable perception of listening room preference occurs with a 2-month listening gap. Bech concluded that the expert listeners used in his test were able to maintain long-term representations of room timbre. However, expert listeners were also used in this test and this was not found. Further, a small tendency towards a contraction of ratings with time can be seen in Bech's results. However Bech's finding highlights the fact that some form of long-term memory for timbre exists. Listeners are able to label loudspeakers and rooms as good and bad consistently over time. Total adaptation does not appear to occur. It is likely that this memory involves the storage of timbre in a categorical form and is different from the memory involved in observing smaller timbral differences [12]-[14]. Further investigation into how timbral memory and other cognitive and physiological processes affect the perception of loudspeaker and room timbre is needed to determine the extent to which researchers should consider the time course of listening when conducting listening tests.

6. CONCLUSION

This study shows that listeners have a tendency to perceive timbral differences between loudspeakers and between rooms as smaller when stimuli are compared using an indirect comparison method, representative of real-world listening. This indicates that adaptation to loudspeaker and room timbre does occur when listening over longer time courses. The time between stimulus presentations may be a factor in the reduction of sensitivity to timbral differences: the removal of time gaps increased perceived differences between rooms. This suggests the involvement of mechanisms sensitive to the time between stimulus presentations, including timbral memory and spectral compensation effects. Response bias did not explain adaptation to timbre: when listeners were directed to pay more attention to stimuli, smaller differences remained with indirect comparisons. Adaptation is therefore not to do with listeners intentionally recalibrating ratings scales. Further research should investigate the effect of time between comparisons on perceived timbral differences. Researchers should be aware of the time course of listening when conducting listening tests.

7. ACKNOWLEDGEMENTS

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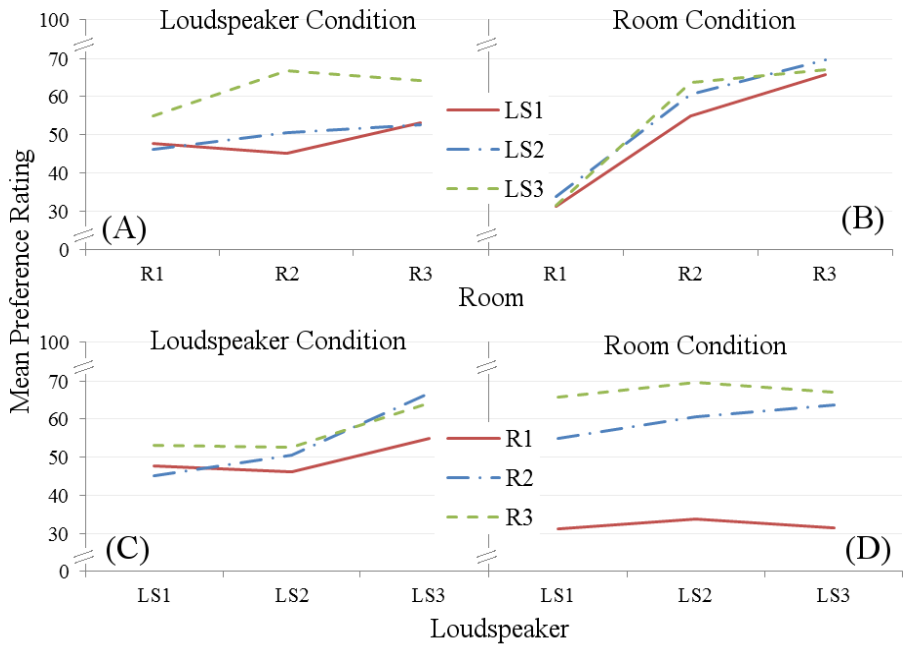

Figure 1: 10 minute condition. Preference ratings for loudspeakers in the loudspeaker condition (A) and room condition (B); Ratings for rooms in the loudspeaker condition (C) and room condition (D).

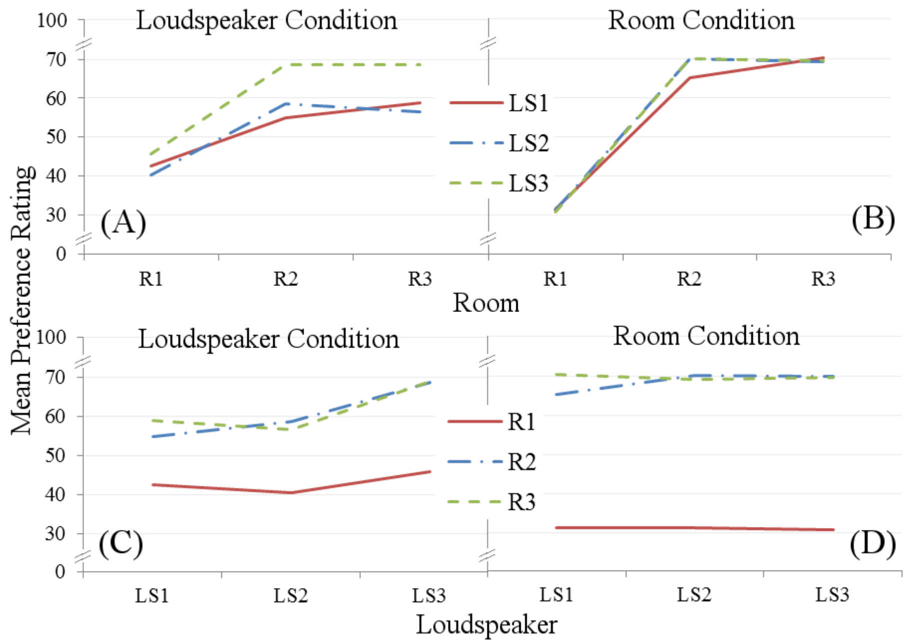

Figure 2: 0 minute time gap condition (no instructions). Preference ratings for loudspeakers in the loudspeaker condition (A) and room condition (B); Ratings rooms in the loudspeaker condition (C) and room condition (D).