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Emotional Impact of Different Forms of Spatialization in Everyday Mediatized Music Listening: Placebo or Technology Effects?

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ABSTRACT

Do the spatial cues conveyed by different audio playback technologies alter the affective experience of music listening or is this rather a matter of quality expectations leading to "placebo effects"? To find out, we conducted a 2-factorial between-subjects design study employing "spatialization type" ('stereo headphones' / 'stereo loudspeakers' / 'live concert simulation') and "spatial quality expectations" ('yes' / 'no') as independent experimental factors. 306 subjects rated the perceived intensity of emotional expression when listening to four different musical pieces as well as the overall audio quality. While we observed significant effects of spatialization type on perceived affective expressivity of music and spatial audio quality, expectation-related placebo effects affected perceived spatial audio quality only. Results are discussed in terms of their significance for music and media research.

1. INTRODUCTION

When listening to music in everyday life, acoustic listening room conditions and playback technologies employed both alter the morphology of the resulting sound field at our ears. The variations introduced by audio media are well-noticeable, as demonstrated in numerous empirical studies [e.g. 1,2]. But do they matter also for the emotional experience of music? Or are presumed modifications in actual affective enjoyment of "mediatized music" just a matter of quality expectations laymen have developed towards certain 'high fidelity' technologies [3]? We tried to find out by conducting an experiment employing *dynamic binaural synthesis* [4] as a means for simulating different possible ways of mediatized music listening in everyday life.

1.1. Research question

Actual effects of audio media technologies on the affective impression of music could be manifold: Different audio formats and compression algorithms, devices and audio playback technologies also exhibit different abilities to transmit the 'expressive cues' of the acoustic musical material considered to be responsible for its affective-expressive impact [5–7]. A further possible explanation for an emotion-evoking role of media in audio communication are biographical memories or socially shared associations symbolically related to the 'sound' (referring to spectro-morphological invariances [8]) of certain historical appliances and formats [9]. To systematically approach the breadth of the problem, we initially focused in the present study on 'spatiality' as one of the most distinguishing technical features of nowadays audio technologies that might lead to a modified affective "physiognomy of music" [10] as well as to technology-related quality expectations. Both may be assumed to be partly determining the 'emotions perceived' [11] when enjoying music in everyday life.

1.2. State of research

Different audio playback technologies offer different types of *spatial cues* when emitting music in terms of 'moving sonic forms' [12]: When *headphone stereo playback* translates inter-channel signal differences into inter-aural signal differences, it delivers a spatially distorted, *internalized* scene image, reducing the intended 'localisation' to a 'lateralization' of the sound sources involved [13]. In contrast, when listening to *stereo loudspeaker playback* in the *sweet spot*, listeners draw on the same spatial cues (foremost ITD, ILD) to perceive the spatial scene as intended by sound engineers (with loudspeakers as a production standard) but may additionally draw on *motion cues* resulting from own head movements leading to an 'externalization' of the rendered auditory scene [14]. Finally, nowadays edge-of-science auralization technologies like *dynamic binaural synthesis* [4] may additionally enrich the transmitted auditory scene by a degree of spatial detail in all 3 dimensions, providing plausible simulations, which cannot be identified as such even in direct comparison with the original, simulated sound field [15]. Since the promise of "high-fidelity" put forward by audio technology marketing claims typically also comprises a preferably transparent transmission of spatial detail of produced virtual musical scenes, expectation-related placebo effects with regard to the spatialization type employed are also theoretically expected.

1.3. Hypotheses

In sum, we hypothesize (A) that the different degree of spatial detail afforded by three prototypical playback technologies (headphones, loudspeakers, binaural auditory scene simulation) not only leads to accordingly increased perceived spatial audio quality but also to an increase in perceived emotional expressivity of music. Furthermore, we assume (B) an additional positive effect of social expectancies related to 'high-end' technologies on spatial quality impression as well as on perceived affective expressivity of music.

2. METHODS

2.1. Musical stimuli

In order to allow for direct comparisons of the impact of different types of audio spatialization, we selected four CD music releases of different genres, valences and production types (table 1) for which a stereo CD production version (44.1 kHz, 16 bit) as well as quasi-anechoic source material in form of single tracks (48 kHz, 24 bit) were available. All selected pieces drew on acoustic instruments only and abstained from additional overdubs and effects, thereby bestowing the intended dynamic binaural live concert simulations with comparable plausibility.

Table 1: musical stimuli, description and technical data

musical piece	description	technical data
Pascale Gautier Quartet: *Contredanse* *(Yolané CD, 2010)*	vibrant latin jazz (original CD production)	4:26m CD audio 6 single tracks
Nick Drake: *River Man* *(Five Leaves LP, 1969)*	sad pop song (self-made sound-alike production)	4:23m CD audio 15 single tracks
Vienna Philharmonics / Daniel Barenboim: *R. Strauß: Annen-Polka* *(Neujahrskonzert 2009)*	happy classical piece (live recording)	4:31m CD audio 16 single tracks
Cleveland Orchestra / Pierre Boulez (2010): *Gustav Mahler* *10th Symphony, Adagio*	dramatic classical piece (live recording)	7:42m CD audio 18 single tracks

2.2. Experimental conditions

In the experiment, *spatialization type* was varied "between-subjects" by letting participants listen to all four musical pieces with one of three possible auralizations:

(1) *"Stereo Headphones:* The original stereo production mix of all four selected musical stimuli played back over headphones.

(2) *"Stereo Loudspeakers":* The dynamic binaural simulation of a living room with stereo loudspeakers playing the original stereo production mix in a standard ±30° stereo setup with a virtual listener positioned in sweet spot. The simulation was realized based on a horizontal dataset of binaural room impulse responses (BRIRs) allowing for a ±80° range of head movements with 2° step size [16] and minimum-phase interpolation [17]. The BRIR data were recorded with the FABIAN binaural robot [18] in a 4.7 x 4.5 x 2.7m living room with parquet floor and large windows, employing a pair of Genelec 1031a active midfield studio speakers for audio playback.

(3) *"Live Concert Simulation":* The dynamic binaural simulation of a musical live performance in a concert hall with the listener positioned centered and 3.9m away from stage. The simulation was based on quasi-aneochic, close-miked single track recordings of the instruments and instrument-groups taking part in the four musical pieces. The audio material was spatialized with the EASE 4.3 software [19] by employing for each instrument virtual loudspeaker models with corresponding directivity [20]. These were generated by drawing on measurements of 3-dimensional directivity patterns of different acoustical musical instruments performed in the anechoic chamber of TU Berlin by using the enveloping surface method with a 32-channel spherical microphone array [21,22]. Virtual loudspeaker models for each instrument were positioned in EASE on stage of a virtual concert hall model (V = 6400 m³, RT = 1.8s) in order to create a plausible instrument setup. Furthermore, a virtual listener was positioned at an optimal spot near stage. The numerically derived reflections of each sound source were weighted with the corresponding measured HRTFs of the FABIAN robot [23] also used in spatialization type (2), for each head over torso position. Finally, an according horizontal BRIR dataset (±80° range, 2° step size) was rendered for the complete virtual scene. The dynamic balancing of the individual (virtual) sound sources was performed by professional sound engineers and inspired by the production sound aesthetics of the CD version.

2.3. Dynamic binaural audio playback

In order to de-confound device-related *quality expectations* from *spatialization type*, the audio signal was played back in all three versions through a Stax SRS 202 electrostatic open circumaural headphone coupled with a Stax driver unit SRM 252 II being fed from an M-Audio Audiophile 192 sound card on a Linux PC system [24]. The binaural signal of version (2) and (3) additionally underwent headphone compensation [25] in order to eliminate headphone-specific influences on playback sound. *Dynamic binaural synthesis* was realized by using the fWonder real-time rendering application [4], using a Pholemus FASTRACK sensor for head tracking, exhibiting a system latency well below the perceptual threshold for dynamic binaural simulations [26].

In order to prevent unwanted confounding due to differing *audio levels* of pieces and *spatialization type,* the rendered binaural signal was captured from sound card output at 0° horizontal head position and measured and adjusted in terms of RMS for each piece and version to reach approximately the same overall sound pressure level. Afterwards, audio level was fine-tuned by members of research group in order to guarantee approximately the same perceived loudness with respect to the dynamic simulation, too.

2.4. Experimental procedure and instructions

For the experiment, n = 306 laymen subjects were recruited via advertisements on paper flyers and electronic mailing lists. Participants were first asked to fill out a computer-based questionnaire on socio-demographic data, affective state and habitual affect-related approach/avoidance behavior (see 2.5.1).

Before start of the listening experiment, contrasting *quality expectations* were evoked in sense of hypothesis B by employing an instructional manipulation: While half of subjects were told by the experimenter to (1) 'just listen and enjoy the music', the other half was additionally told before to (2) 'please pay attention to peculiarities in spatial audio quality due to the special new audio technology used in this experiment', thereby introducing a "between-subjects" instructional manipulation.

Subjects received a sleeping mask and where let alone in the shaded laboratory in a comfortable leather armchair. They then listened to the four musical pieces in random order through the Stax with mounted tracking sensor which was connected to a PC in the next room running the FWonder binaural rendering client. After end of each piece, subjects were instructed through headphones to rate the perceived emotional expression of the piece by the questionnaire instrument presented to them on a computer screen. After listening to all four pieces, participants filled out a computer-administered audio quality questionnaire and then left the experiment after receiving a monetary compensation.

2.5. Measurements

2.5.1. Control variables

Before start of the experiment*, socio-demographics* of participants were asked for on binary (sex / higher education) and metrical level (age). Furthermore, current *affective state* was measured by employing the German positive-negative affect schedule (PANAS) [27]. Finally, h*abitual affect-related approach / avoidance behavior* was measured by employing the German need-for-affect scale (NFA) [28].

2.5.2. Dependent variables

After listening to each musical piece, *perceived emotional expression* was measured by asking participants to rate perceived intensity of emotional expressivity of the musical piece on a self-constructed, 15 items comprising 5-point scale reaching from “not at all” to “very much” (cf. table 2 for item list) that was meant to represent the four quadrants of the emotional circumplex [29].

Table 2: perceived emotional expression instrument

factor dimension	items	item weights
Expression 1: happiness & joy	pleasure	1.0
	solemnity	.75
	humor	.68
Expression 2: love & desire	love	1.0
	tenderness	1.0
	hope	.61
	desire	.75
Expression 3: sadness & pain	sadness	1.0
	disappointment	.62
	regret	.66
	pain	.91
Expresion 4: anger & tension	anger	.71
	outrage	.74
	irritation	.92
	tension	1.0

By the end of the listening experiment, *perceived audio quality* was measured by asking participants to fill out a self-constructed 6 item comprising 9-point semantic differential (cf. figure 2 for item list) inspired by Gabrielsson & Sjögren [30] that represented three different sound quality dimensions (‘*transparency*’, ‘*sonority*’, and ‘*spatiality*’). .

2.6. Statistical analyses

Statistical analysis was conducted by means of structural equation modeling (SEM) employing the MPlus 6.1 software package [31], using maximum likelihood estimation with robust standard errors (MLR) and missing data imputation. Initially, confirmatory factor analyses (CFA) were conducted for assessing dimensionality and estimating reliability, average extracted variances and overall fit of the latent measurement models. Afterwards, structural hypotheses A and B were tested with the classical SEM approach for *perceived audio quality* and with a repeated measurement SEM (bi-factor approach) [32] for *perceived emotional expression of music*. In order to test for orthogonal effect contrasts between experimental conditions, the 3-level treatment variable was dummy-coded with employing *stereo headphones* (HP) as the baseline condition. While neither differences between stereo unit and live performance nor factor interactions were tested explicitly, both structural models employed participants' socio--demographics (sex, age, education), as well as PANAS and NFA scores as control variables. On basis of these, corrected factor means for experimental groups were estimated in terms of MANOVA-logics.

3. RESULTS

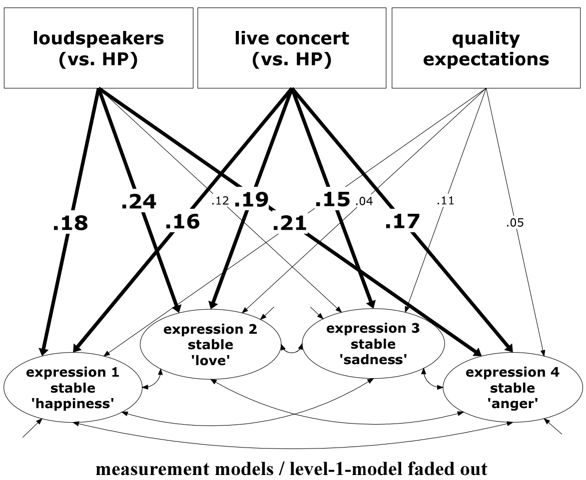
3.1. Sample structure & experimental design

Of the n = 306 subjects, 55 % were female and 60.1 % had a college degree or higher education. Age was asymmetrical distributed from 18 – 78 with M = 40.1 (SD = 14.3) and Med = 38.6 (IQR = 23 [28..51]). Based on socio-demographics, subjects had been systematically dispersed equally across the three *spatialization types* by the experimental software and then randomly allocated with 3:2 odds to either instructional manipulation, resulting in an unbalanced 3 x 2 experimental design (table 3). Possible bias due to unobserved heterogeneity in subpopulations was accommodated for by employing control variables (age, sex, education) as covariates in both structural models and conducting Levene tests of variance homogeneity across groups (all p > .1).

3.2. Model 1: perceived emotional expression

The *perceived emotional expression* longitudinal CFA employing the bi-factor approach (decomposing stable from time-varying variance components by assuming tau-equivalent measurement models across measurement occasions) reached a satisfying model fit with X^2 = 2886.448; df = 1596; p < .001; RMSEA = .051; SRMR = .082 (cf. table 2 for unstandardized item weights). A linear mixed model with repeated measurements and covariates was employed afterwards in order to test structural hypotheses. Its level-2-part (subject level) explains the piece-invariant, 'stable' parts of the expression factor scores (figure 1) separated from the song-specific random effect. The estimation showed significant (p < .05) paths deriving from *spatialization* dummys, while there were no significant effects of *quality expectations* on any of the four *perceived emotional expression* factors. Apart from the path from *stereo loudspeakers* to *sadness*, both *stereo loudspeakers* and *live concert simulation* lead to significant (p < .05) increases in perceived emotional expressivity on each of the four expression dimensions with comparable magnitude (βs ranging from .15 to .24). Altogether, the model was able to explain about R^2 = 36 % variance in each dimension of piece-independently perceived emotional expression scores.

Figure 1: SEM-results for perceived emotional expression model, level-2 model part (subject level), significant (p < .05) effect paths of spatialization type are set in bold. Figures are standardized regression coefficients



measurement models / level-1-model faded out
***control variables* (faded out): age, sex, education**
NFA-seek, NFA-avoid, PANAS-NA, PANAS-PA

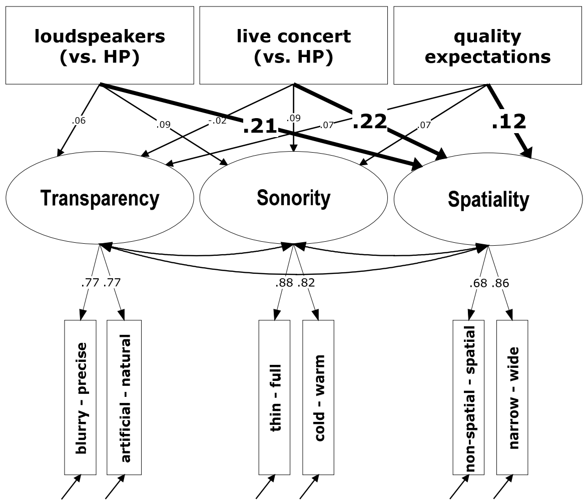
Table 3: experimental design (no. of subjects/condition)

spatialization type:	**quality expectations 'no'**	**quality expectations 'yes'**
stereo headphones	n = 59	n = 33
stereo loudspeakers	n = 57	n = 43
live concert simulation	n = 65	n = 49

3.3. Model 2: perceived audio quality

The *audio quality* CFA conducted reached an exceptionally good model fit with X^2 = 9.309; df = 6; p = .16; RMSEA = .043; SRMR = .018; CFI = .992. All three factor variables exhibited satisfying reliability and variance extraction, with *transparency*: CR = .74 / AVE = .59; *sonority*: CR = .84 / AVE = .72, *spatiality*: CR = .75 / AVE = .60. The general linear model with covariates employed afterwards to test structural hypotheses (figure 2) exhibited significant (p < .05) regression paths from *spatialization type* pointing to the *spatiality* dimension only ($\beta_{loudspeaker}$ = .21 / β_{live} = .22). There were no significant effects of *spatialization type* on either *transparency* or *sonority*, and also *quality expectations* lead to significant (p < .05) increases (β = .12) in *spatiality* only. Nevertheless there were some correlations between *sonority*, *transparency* and several covariates. Altogether, the model was able to explain about R^2 = 19 % variance in perceived spatial sound quality.

Figure 2: SEM-results for perceived audio quality model, significant (p < .05) effect paths of spatialitation type and quality expectations are set in bold. Figures are standardized regression coefficients



***control variables* (faded out): age, sex, education**
NFA-seek, NFA-avoid, PANAS-NA, PANAS-PA

4. DISCUSSION

4.1. Effects of spatialization type (hyp. A)

As results in figure 1 show, when listening to four music pieces of different genres and valences, participants perceived binaural *stereo loudspeaker* and *live concert simulation* as being more intense on all four dimensions of *perceived affective musical expression* compared to *stereo headphones* reproduction. The same applies for *perceived audio quality* as shown in figure 2. Thus, hypothesis A seems to be justified: A higher degree of spatial cues in audio playback leads to an increase in perceived emotional expression of music additional to an increase in perceived spatial quality. Since the effects of spatialization types (2) and (3) exhibit nearly similar magnitude, we conclude that increases found must be rather due to the additional *motion cues* that both simulations were able to evoke, than due to the extended *spatial detail* unique to the binaural *live concert simulation*. Furthermore, we interpret the fact that neither *transparency* nor *sonority* were touched by s*patialization type* in that we were successfully able to deconfound *spatialization type* from auralized musical content in terms of perceived ‘production sound’.

4.2. Effects of quality expectations (hyp. B)

The only significant effect of the instructional manipulation pertained to an increase in *perceived spatial audio quality* (regardless of *spatialization type* administered). Insofar manipulation did not affect other dimensions of sound quality perceived, it proofed successful in terms of specificity on *spatiality*. On the other hand, it did not affect any of the 4 dimensions of perceived affective expression of music, thereby falsifying hypothesis B in terms of *perceived emotional expression*. Quality expectations seem to leave the expressional dimension of music untouched, while leading to an increase in attributed quality only. We carefully conclude from results that technology-related placebo effects only apply to perceived audio quality but not to perceived emotional expressivity of music.

4.3. General discussion

The present experiment drew on dynamic binaural simulations to perform inquiry on questions from music psychology that pertain the role of media technologies in modulating the aesthetic experience of everyday music listening. As results show, placebo effects in perceived sound quality due to socially induced expectations with regard to media technologies may very well occur. But these appear not to influence the affective musical impressions themselves. Conversely, different audio spatialization technologies practically employed for listening may lead to more or less emotionally expressive musical experiences. The respective effects found seem to rely more on the additional phenomenal quality of *externalization* itself the playback technology allows – the feeling of being part of an auditory scene surrounding one’s own body – than on improvement in spatial auditory scene detail. This result may be related to similar media psychological findings from presence research in the visual realm that stress the importance of sensory-motor inclusion of subjects for creating plausible audiovisual simulations [33].

Limitations in interpretation of results are threefold: Firstly, due to the unbalanced experimental design, not all effect paths in the models could be tested with the same statistical power, rendering overseen small significant effects possible. In order to compensate for that, additional experiments are conducted right now by our research group. A further limitation may lie in still a lack of specificity with the instructional manipulation: Maybe there exists another type of expectation manipulation that would better be able to also affect perceived emotional expression. Finally, even if research of our group shows that laymen are unable to differentiate real sound fields from dynamically simulated speakers above chance (Lindau & Weinzierl 2012), there is a theoretical limitation with regard to possibilities to generalize from mere sound field simulations in the experimental laboratory to the effect of whole material media appliances in social reality.

Apart from that, results have important consequences for music psychology research drawing on audio features, e. g. employing continuous measurement response techniques [34]: All effects found have to be regarded in light of the playback technologies employed. Furthermore, the results at hand seem to also have large theoretical implications for the social-construction-of-technology approach in social science and technology studies (STS) [35], the emerging field of sound studies [36], and also mediatization research [37] that all try to understand the interplay of media technologies and related performance claims and users practices: Different audio media technologies afford different types of affective-aesthetic experiences with regard to the *spatial cues* they are able to emit. These are due to real physical differences in evoked sound fields and barely (if at all) dependent on socially acquired quality attributions.

4.4. Methodological outlook

Dynamic binaural synthesis [4] allowed us to test for technologies´ impact on perceived affective expression of music related to different degrees of *spatial cues* while holding other factors (e. g. *visual appearance* of devices and related *quality expectations*) constant. The approach demonstrated could be extended to other types of playback technologies or playback rooms (different types of HiFi Stereo appliances and speakers, different types and sizes of playback rooms / concert halls). This would allow future endeavors in music and media research to detect possible other 'technology effects' on emotional aesthetic quality of music apart from spatiality.

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