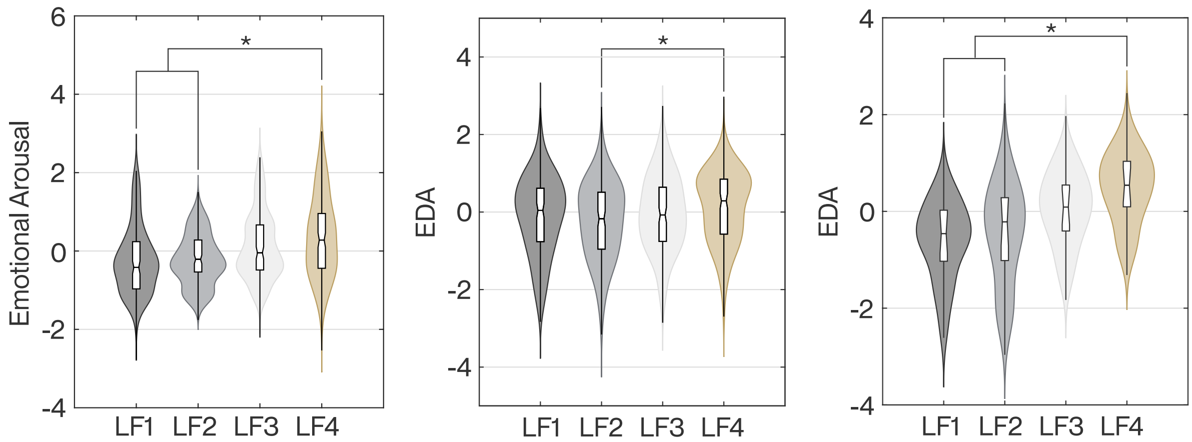
ENHANCED LOW-FREQUENCY CONTOURS DRIVE STRONGER EMOTIONAL RESPONSES TO MUSIC

. Bass amplification has an emotional impact on music listening that is comparable in magnitude to the music itself, highlighting the critical role of sound system design and mixing in shaping the overall experience.

. The effect of bass appears to vary with musical genre, aligning with standard sound engineering practices where certain styles are known to require more substantial low-frequency support.

THE MEASURED EFFECT OF BASS ON THE EMOTIONAL RESPONSE TO MUSIC



Intensity of the measured emotional response to music as a function low-frequency (LF) amplification.
Left: emotional arousal as reported by the listeners, on average over music genres,
Middle: physiological response (electrodermal activity—EDA) on average over music genres,
Right: physiological response for electronic dance music (EDM).
Note: stars indicate statistically significant differences between data groups.

The results of our study indicate that increasing the amplification of low frequencies while keeping the loudness constant significantly impacts the listeners emotional response to music. In short, the stronger the bass, the stronger the emotion. This effect was observed through listener reports regarding their emotional state, on average over every music track. We observed the same effect through physiological indicators of emotional arousal, specifically Electrodermal Activity (EDA). However for EDA the effect is only visible for certain tracks used in the experiment (e.g. Electronic Dance Music). Thus, the impact of bass on the emotional response to music may depend on the style of music.

Interestingly, we also observed that the relative impact of LF amplification on the emotional response was only 30% smaller compared to that of the musical content. Analysis of the emotional arousal reported by listeners showed that the music track explained approximately 10% of the variance, while low-frequency amplification accounted for 6.4%. Likewise, the music track contributed to 3.2% of the variance in the EDA data, while LF amplification contributed 2.1%.

IMPLICATIONS FOR AUDIO PROFESSIONALS

These results highlight how important sound system design and mixing are to the overall listening experience. In other words, a great music performance can see its impact on the audience magnified — or attenuated — by a significant amount depending on audio engineering decisions. The fact that different music styles may require different system designs and settings is consistent with practices commonly observed in the field, where heavier low-frequency resources are expected for rap or EDM concerts than for jazz or orchestral music, for instance.

LISTENING TEST

To investigate the impact of bass amplification on emotional responses to music, we conducted a controlled listening test. A total of 21 listeners took part in the experiment. Participants were seated comfortably, facing an L-Acoustics sound system comprising two Syva and two Syva Sub speakers. Their primary task was to listen attentively to a series of musical stimuli played through the system. The test included thirty-two stimuli, derived from eight distinct music excerpts, each processed to produce four different low-frequency (LF) amplification profiles (LF1–LF4) with progressively enhanced bass content, while maintaining consistent overall loudness.

We measured the participants' emotional reaction to music stimuli using two different methods:

1. Electrodermal activity (EDA) — We monitored the listeners' skin conductance using electrodes placed on their fingers.

2. Direct report — Listeners were asked to press a feedback button whenever they felt emotionally aroused by the music.

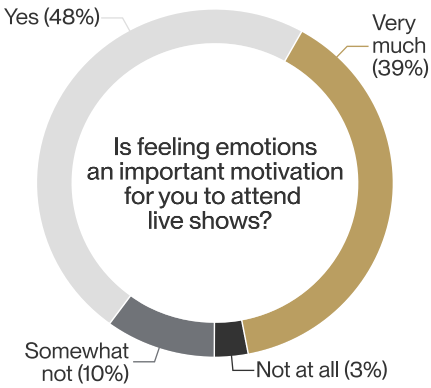
We then analyzed the feedback button and EDA data to investigate the impact of the LF amplification profile, while controlling for the influence of the music track.

Listening test set up

ENHANCING THE EMOTIONAL DIMENSION OF LIVE MUSIC

Music is a powerful vector of emotions, capable of evoking a wide range of feelings that deeply resonate with listeners. Emotions are frequently cited by concertgoers as a key motivation for attending live music events, where the collective atmosphere can intensify the emotional connection shared among the audience. The thrill of a live performance, the energy of the crowd, and an immersive sound environment all contribute to a heightened emotional experience.

One reason music is at high volumes during concerts is to enhance the audience's level of engagement and excitement. Yet intense sound levels, while effective in creating excitement, can lead to hearing damage and discomfort for some attendees. This highlights the need to explore alternative strategies for enhancing the emotional impact of music without relying on potentially harmful volume levels. Our findings suggest that aspects of sound system design and mixing techniques offer promising avenues for achieving this goal.



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GLOSSARY

Arousal: State of being energized, excited, alert.

Valence: The property specifying whether emotions are positive, negative or neutral.

Low frequencies/bass: Frequencies in the 20-200 Hz range.

EDA: Electrodermal activity. Consists in measuring variations in skin conductance using electrodes.

ANNEX 1: EMOTIONAL RESPONSE MEASUREMENT MODALITIES

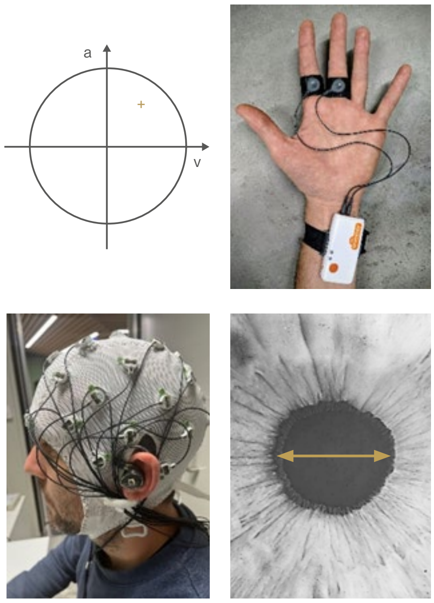
Emotions are complex reactions that involve behavioral, psychological and physiological phenomena. Because emotions are multidimensional, no single approach can comprehensively capture their nature and intensity. Nevertheless, the different facets of emotions can be measured separately using specific techniques:

. The psychological state of an individual can be probed using surveys and scales. A common method consists in employing a graphical user interface featuring two axes, one for valence and one for arousal, which the individual uses to report his own emotions.

. Different physiological signals can be measured to monitor the emotional state of a person. For instance, EDA consists in measuring skin conductance, which tends to increase when emotions occur, triggering the release of sweat. Another example of physiological measurement is EEG, which employs electrodes to monitor brain activity. Many other modalities exist, such as pupillometry (measuring the diameter of eye pupils), heart rate monitoring, etc.

. Lastly, the behavior of an individual provides insight into one's emotional state. For example, face expressions or body movements can be recorded and analyzed.

Note that each measurement method comes with its own advantages or constraints. Some, like EEG, typically require a laboratory environment, while others can be used more freely.



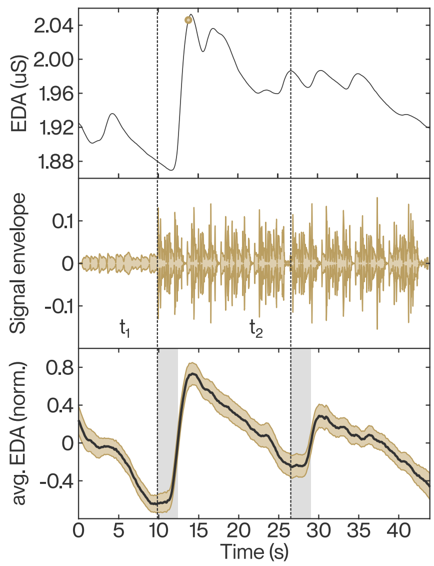
Examples of emotional response measurement modalities
From left to right and top to bottom: self-report, EDA, EEG, pupillometry.

ANNEX 2: ELECTRODERMAL RESPONSE TO MUSIC

EDA reflects a person's level of emotional arousal, i.e. how excited or energized they feel. As such, it has been widely used across various fields, including clinical psychology, marketing, and musicology. EDA signals are inherently noisy, as they can fluctuate due to factors such as sensory stimulation, temperature changes, or spontaneous cognitive activity. Yet, when listeners are focused on the music, meaningful correlations can often be observed between musical stimuli and skin conductance responses.

Please refer to the figure on the right. The upper section displays the EDA signal recorded from a listener during playback of the music excerpt illustrated in the middle plot. Approximately 2.5 seconds after time point t_1, we observe a sharp increase in skin conductance, coinciding with a musical "drop" at the end of the song's introduction. The circular marker near the peak of the EDA signal indicates the moment the listener pressed the feedback button, suggesting conscious recognition of an emotional surge. Throughout the duration of the stimulus, several secondary peaks are visible, which may or may not be directly related to the musical content.

The lower plot shows the average EDA response across all listeners for the same musical excerpt. Two prominent peaks appear approximately 2.5 seconds after time points t_1 and t_2, respectively. This suggests that, on average, listeners exhibit physiological reactions to specific musical features, demonstrating that EDA can serve as a reliable indicator for tracking emotional engagement with music.

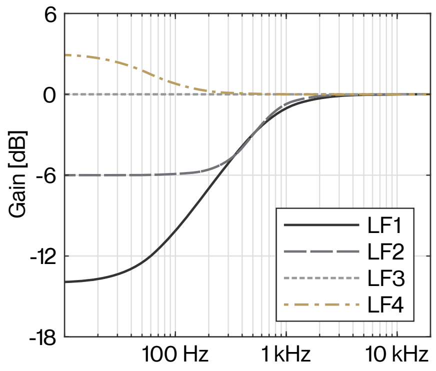


Electrodermal response to music.
Top: EDA signal; Middle: music signal waveform; Bottom: average EDA response. Time points t_1 and t_2 correspond to the "drop" and vocals entrance, respectively.

ANNEX 3: GENERATION OF THE LISTENING TEST STIMULI

In order to control for the influence of the musical content, we used extracts from eight tracks with various music styles. The tracks were the following:

- “Angel”, by Sara McLachlan (Pop, Folk)
- “Am I not Merciful?”, by Hans Zimmer (Epic, Orchestral)
- “Where we’re going”, by Hans Zimmer (Orchestral, Electronic)
- “Rammstein”, by Rammstein (Metal, Industrial)
- “The Message”, by NAS (Rap, Hip Hop)
- “Be Yourself”, by Ayu Acid (Electronic)
- “Echoes”, by Pink floyd (Prog. Rock)
- “Dear Limmertz”, by Azymuth (Jazz, Funk)



EQ functions corresponding to the 4 LF amplification profiles.

The four LF amplification conditions (LF1-4) were implemented by filtering the original music tracks with filters designed using the LF Contour and Zoom Factor tools in L-Acoustics’ LA Network Manager. Note that LF3 corresponds to the default preset for this system with no filter applied. The 32 stimuli were equalized in loudness and played back at approximately 90 dBA, in a random order.

ANNEX 4: DATA PROCESSING AND STATISTICAL ANALYSIS

For the EDA signals, we first segmented the signals into epochs corresponding to each stimulus. We then applied the EDA positive change method (EPC), to obtain one EDA score from each epoch. EPC consists in accumulating all positive variations of skin conductance over the considered time window. Regarding the feedback button data, we simply counted how many times the button was pressed for each participant and stimulus.

Factor	Sum sq.	D.o.f.	Mean sq.	F	p
Track	45.778	7	6.540	4.723	**0.0001**
Cond	29.458	3	9.819	10.643	**0.000**
T*C	7.625	21	0.363	0.598	0.9196
Error	404.393	512			

Factor	Sum sq.	D.o.f.	Mean sq.	F	p
Track	16.256	7	2.322	2.806	**0.0091**
Cond	10.532	3	3.511	3.917	**0.0140**
T*C	7.625	21	1.386	1.484	0.0799
Error	454.058	512			

ANOVA results for the data acquired during the experiment. Left: reported emotional arousal; Right: EDA.

For data analysis we primarily used repeated analysis of variance (ANOVA). The tables above display the results of two-way ANOVA for factors “Track”, “LF condition” and their interaction on the datasets acquired during the experiment. The p-value represents the probability of observing the given data, assuming that the factor being tested has no actual effect. An effect is generally considered statistically significant when the p-value is less than 0.05. In the examples above, both the music track and the LF condition have a statistically significant effect on reported arousal and EDA. However, their interaction does not have a significant impact.

In addition, the “Sum square” values indicate how much of the data variance is explained by each factor. Dividing the sum-square value for the track factor by the sum of all sum-square values, we see that the LF condition accounts for 6.4% of the variance for the reported arousal and 2.1% for EDA, respectively. In other words, although there is a measurable impact of bass, it is relatively small, and a large portion of the observed fluctuations are attributable to other factors, such as differences between subjects, measurement noise, etc. On the other hand, the sum square values for the LF condition factor are only about 30% lower than for the Track factor. This indicates that the impact of the LF amplification profile on the emotional response to music is in the same order of magnitude as that of the musical content.