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INFLUENCE OF PARTICIPANT TRAINING ON THE DISCRIMINABILITY OF CLARITY CHANGES

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ABSTRACT

Over the last few decades, there has been a growing interest in the field of tonal discrimination to study the perceptual differences between people who have received extensive musical training and those who have not. These studies have shown that musicians appear to have superior auditory discrimination skills. This raises the question of whether these allegedly superior listening skills are also noticeable when assessing room acoustics.

In order to investigate the relationship between musical training and room acoustic parameters, this research focused on the parameter of musical clarity C_{80}. The analyses carried out aimed to determine whether its perception depends on the musical training of the listener. The data used for the evaluation came from the results of a perceptual test in which two groups of participants had to judge the changes in the musical clarity level of a series of stimuli. One group consisted of people trained in music, the other consisted of inexperienced listeners.

The results show that trained participants were significantly better at detecting changes in clarity, while untrained participants struggled more with this task. These results suggest that musical training improves the ability to perceive changes in the acoustic properties of a room.

Keywords: *musical training, musical clarity C80, perception, listening test, room acoustics.*

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1. INTRODUCTION

Several studies focused on tonal discrimination have investigated the differences between the auditory abilities of musicians and non-musicians in listening tests [1–5]. These studies were driven by the prevalent belief that people with musical training possess enhanced listening skills. The main interest in the task of tonal discrimination lies in the fact that the ability to discriminate musical pitches is fundamental for the interpretation and analysis of music.

All the aforementioned investigations are based on listening tests in which two groups of participants – one consisting of participants with extensive musical training and another of naive participants - performed the same task. The objective was to ascertain whether there were significant differences in the performance and results of the two groups.

One of the first studies to address this issue involved the use of a listening test to evaluate the relationship between tonal discrimination and musical training, as well as age [1]. Participants were tasked with identifying whether the presented tone remained constant or underwent an ascending or descending modulation. The results demonstrated that both age and musical education were positively correlated with the accuracy of the responses.

Almost two decades later, the subject was reexamined by Spiegel and Watson [2], who sought to further evaluate the effect of musical training on frequency discrimination abilities. The participants were tasked with comparing six base tones with ascending frequency variations, and the results demonstrated a clear relationship between the musical training of the participants and their performance on the task. A noteworthy finding was that half of the non-musicians demonstrated tonal discrimination thresholds comparable to those of the musicians. This phenomenon was also observed in the results of the listening test carried out by Kishon et al., in which they evaluated the discrimination ability of participants using non-musical tones [3]. In this case, only 29% of the non-musicians demonstrated a discrimination threshold similar to that of the musicians. Nevertheless, the publication as a whole demonstrated a clear relationship between musical training and pitch discrimination ability. It should also be noted that, in this research, non-musicians who underwent repeated testing showed improved performance, implying that training can significantly enhance auditory discrimination skills.

Micheyl et al. revisited this area of research, prompted by the unexpected findings of earlier studies [4]. They were particularly intrigued by reports indicating that the frequency discrimination thresholds of musicians and non-musicians differed by only a factor of two, and that non-musicians could attain performance levels comparable to those of trained musicians after less than an hour of practice. However, their own study revealed more pronounced differences: musicians exhibited frequency discrimination thresholds six times lower than those of non-musicians. Furthermore, even after two hours of targeted practice, the average threshold for non-musicians remained four times higher.

The relationship between musical training and listening skills was also investigated by Oxenham et al., in this case focusing on masking thresholds [5]. Despite finding no significant differences in energy masking thresholds, the study found that musicians demonstrated notably lower informational masking thresholds. This finding suggests that musical training may have equipped musicians with superior analytical listening skills.

Whilst there are some inconsistencies between studies, a common finding emerges: musically trained individuals consistently demonstrate superior pitch discrimination skills compared to non-musicians.

In the field of room acoustics, perceptual evaluations frequently involve both trained and untrained participants. Despite this, there is a lack of research specifically investigating the impact of musical education on perception. The most notable research in this area was carried out by Kuusinen and Lokki [6] and von Berg et al. [7]. The research of Kuusinen and Lokki identified that acoustic and musical experience can facilitate the successful completion of certain discrimination tasks [6]. These tasks involved comparing impulse responses in which the stimuli have been obtained using the same sound signal. However, when the sound signals employed between stimuli differ, this advantage is not as evident. Von Berg's research focused on how different factors that could be considered within the concept of musical expertise affected the detection of changes in reverberation time and spectral envelopes [7]. This study demonstrated that certain factors, including musical training, acoustic knowledge, and experience in music recording, are positively correlated with better performance on these tasks.

The present study aims to systematically evaluate the differences in auditory judgments between two clearly differentiated groups of participants, one musically trained and the other naive, in response to variations in the acoustic characteristics of impulse responses, specifically, in the musical clarity, measured by the parameter C_{80}. This task is highly relevant in research that focuses, for example, on determining the Just-Noticeable Difference (JND) of the acoustic clarity parameters C_{50} and C_{80}. Some of the research focused on this task [8–12] has included participants with varying levels of musical experience, ranging from concertgoers to professional musicians, while others have used trained listeners exclusively. Even so, these studies have not explicitly evaluated whether training influences perception outcomes.

The variation in participant selection criteria used in previous studies underscores the need for further research in this area. To address this gap, a comprehensive statistical comparison was performed using Cochran-Mantel-Haenszel (CMH) analyzes to assess how participants with different levels of musical education perceive the parameter of musical clarity C_{80}. The data used in the analysis came from a listening test that was performed by 36 participants, half of them with at least 10 years of musical experience and the other half without previous musical training. Participants were asked to rate the clarity of a total of 30 stimuli generated by convolution of five musical motifs with six impulse responses of different levels of C_{80}.

The objective of this listening test and the subsequent CMH analyzes is to determine whether musical training is a relevant factor in the perception of the acoustic characteristics of a room using sound samples.

2. EXPERIMENTAL SET-UP

2.1 Stimuli generation

The objective of the listening test was to ascertain whether there was a discrepancy in the performance of musically trained and non-trained participants when discriminating changes in the clarity of a musical stimulus. The musical stimuli employed in this study were derived from the convolution of five musical motifs, characterized by varying stylistic attributes, with six impulse responses of varying C_{80} levels.

2.1.1 Musical motifs

A large number of musical motifs were chosen to test whether the musical characteristics of the pieces could also influence the assessments of the participants. The musical motifs were selected according to their instrumentation, *tempo* and style characteristics. The first musical motif (MM1) consists of a 24-second segment from Mozart's Flute Concerto No. 1. This excerpt is characterized by a rapid tempo and numerous short-duration notes. The second motif (MM2) is an 18-second segment from Fauré's Élégie for cello and orchestra. This segment, performed exclusively by the cello, is distinguished by a deliberate slow tempo and long, sustained notes. The third motif (MM3) is a 20-second excerpt from the Prelude to Verdi's La Traviata. This orchestral piece is characterized by a slow tempo and a clearly defined accompaniment. The fourth motif, MM4, is a 14-second excerpt of liturgical chant from the Office of the Dead of the Hispanic Rite. This is performed by a five-voice male choir. The fifth and final motif (MM5) is a 10-second orchestral excerpt from the fourth movement of Beethoven's Ninth Symphony. This fast-paced segment features layered melodic lines and pronounced percussion elements. A more detailed description of the musical motifs and analysis of the influence of the musical motif on the perception of clarity is presented in [13].
In listening tests, the duration of the stimuli should be long enough for the participants to assess the acoustic characteristics of the room without becoming fatigued [14]. In this test, musical excerpts ranged from 10 to 24 seconds to ensure each ended with a conclusive cadence. This decision aimed to provide a natural sense of closure, avoiding potential listener discomfort or distraction that might result from abrupt or unresolved endings [13].

2.1.2 Impulse response simulation

Given that the aim is to evaluate the discriminability of changes in the level of clarity, it was desirable to consider a large number of stimuli with different C_{80} values. To determine the JND of C_{50}, Bradley [9] sets a level of C_{50} as the base case scenario. This level is then compared with other sound fields that have C_{50} level steps of 0.0; 0.5; 1.0; 1.5; 2.5 and 4.0 dB with respect to the base case. These clarity steps were also used in the investigations of Ahearn and Vigeant [10, 11]. These steps were deemed suitable for our investigation as, based on current state of the art, the evaluated changes in clarity should be noticeable in the majority of cases.
The impulse responses used to generate the stimuli for the listening test were obtained by virtual simulation. The base case level of C_{80} used in our research corresponds to the unmodified virtual model of a concert hall, which was obtained from the database of the acoustic modeling software Odeon®. In the software, the hall is called *ElmiaRoundRobin2* and simulates the acoustic behavior of the Elmia Congress and Concert Hall in the city of Jönköping (Sweden). The concert hall has a volume of 12,520 m^3, a T_{20} of 2.21 s and a C_{80} of -1.75 dB.
In order to obtain the desired C_{80} steps, the model was modified. These modifications involved adjusting the absorption coefficients of the room materials to make them progressively more absorbent. These modifications were applied uniformly across all room materials to maintain the spatial impression of the room, as it is understood that alterations in the spatial impression of a room can influence the perception of its clarity [15]. The C_{80} values of the impulse responses were obtained using Odeon®. These were calculated according to the specifications of ISO 3382, with the C_{80} values for the 500 and 1000 Hz octave bands being averaged. Finally, a range of C_{80} levels from -1.75 to 2.30 dB was achieved.

2.1.3 Convolution method

Before the convolution, the musical motifs were level normalized according to their RMS value to ensure comparability between them. This was due to previous research finding a negative correlation between loudness and clarity [16]. Following this, the stimuli were obtained by convolving the normalized musical motifs with the six simulated impulse responses. The convolution was performed using the auralization tool available in Odeon®. The combination of one of the head-related transfer functions (HRTF) available in the software with the inverse filter of the employed headphones resulted in a total of 30 binaural stimuli. The auralization configuration was kept constant for all stimuli.

2.2 Criteria for the selection of subjects

As the aim of this research was to evaluate the impact of musical training on participants' ability to perceive clarity changes, two participant selection criteria were defined.
In the case of untrained participants, it was decided that

these would be people who had never received any musical education beyond that studied in secondary school. For trained participants, it was determined that they should have, at a minimum, a Professional Intermediate-level diploma in Music, which is equivalent to a 10-year classical music education in a Professional Music Conservatory. Furthermore, trained participants were required to continue to study music or work in a related field at the time of the test. Participants in both groups had to be within the same age range and have comparable general educational backgrounds.
The group of untrained participants consisted of 18 people with no previous musical experience. Half of the group were women, and the ages of the participants ranged between 20 and 30 years.
The trained participant group also consisted of 18 people, 13 of whom were women. The ages of the participants ranged from 18 to 25 years. Six participants were pursuing a Superior-level degree in musical performance, one had a Superior-level degree in orchestra conduction, and the remainder had an Intermediate-level diploma in musical performance. The subjects had an average of 11.5 years of musical experience.

2.3 Listening test specifications

The listening test used a five-point Likert scale to assess the perceived clarity of the stimuli. This categorical scale required participants to select from fixed, labeled response options. The decision to use five points was informed by prior research showing that increasing the number of scale points beyond six adds complexity without improving accuracy [17]. Furthermore, research by Farina highlighted the importance of including a central option, supporting the use of an odd-numbered scale [18].
The Likert scale labels followed the order specified in the ISO 4121 standard. Participants were asked to indicate how high they considered the level of clarity of each stimulus to be. The response options were, from left to right: "*not at all high*", "*slightly high*", "*moderately high*", "*very high*" and "*extremely high*".
The listening test was divided into five parts, one for each musical motif. Within each part, the participants were presented with the six stimuli corresponding to one of the musical motifs convolved with the six impulse responses with different C_{80} values. Participants were first required to listen to all stimuli before starting to respond. This was done so that they would have a reference to the range of variability in the room and be aware of the most extreme

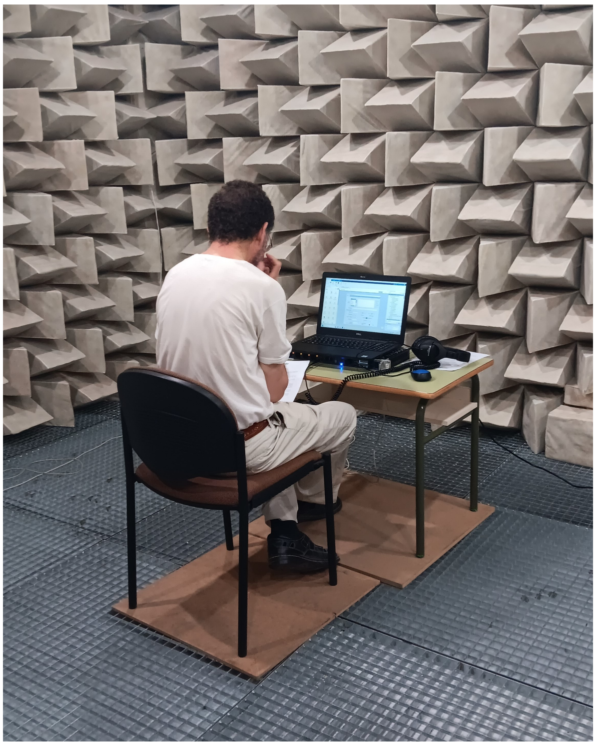

Figure 1. Photograph of one of the participants performing the listening test in the UPM anechoic chamber.

C_{80} values. This would facilitate subsequent scaling and avoid non-selection of the extreme scale positions [19]. Once all stimuli had been listened to, the response section of the interface was activated, and participants could listen to the stimuli again as many times as they wished until they were confident of their scaling. The order of presentation of the stimuli (i.e., musical motifs and impulse responses of varying clarity) was randomized for each participant to ensure statistical independence of the data.

2.4 Listening test procedure

The listening test was carried out in two different locations. One was a quiet rehearsal room at the Conservatorio Superior de Música of Murcia (Spain) and the other was the anechoic chamber at the *Campus Sur* of the Universidad Politécnica de Madrid (Spain) (see Fig. 1). Thirteen of the trained participants took the test at the first site. All other participants took it in the anechoic chamber.

The sound stimuli were presented through open-back circumaural Sennheiser HD-650 headphones. The stimulus playback level was fixed at the beginning of the test and could not be changed. The average stimulus playback level was 76.7 dB, the lowest level reached was 72.0 dB, and the highest was 78.9 dB. The differences between the maximum and the minimum levels are due to differences caused by variations in the impulse responses and by the dynamics of the musical motifs.
Participants were first asked to complete a questionnaire that collected basic demographic and musical background information, such as age, gender, and musical training. This served both to inform later data analysis and to help participants acclimate to the testing environment. Afterwards, they received a written instruction sheet detailing the purpose of the listening test, the response procedure, the definition of clarity, and how their data would be handled. Providing written instructions helped minimize potential bias from the direct researcher-participant interaction.
Clearly defining the subjective quality being assessed in a listening test is crucial to ensure consistent understanding among participants [18, 20]. Misinterpretation, especially of terms that may differ in meaning between acoustics and music, or be unfamiliar to those without musical training, can negatively impact test results. To avoid this, the study used Lindau's definition of clarity in his acoustic terminology glossary [21], which was translated into Spanish and included in the instruction sheet.
After reviewing the instruction sheet and addressing any questions, participants completed a training session designed to familiarize them with the test interface, response method, and overall procedure. This session used a set of practice stimuli, clapping sounds convolved with six different impulse responses representing varying levels of clarity, which were not part of the main test. Participants were guided through the listening and response process. Once the training was completed and no further doubts remained, the main listening test began.

3. STATISTICAL ANALYSIS

The data derived from the listening test included 30 discrete scores from 1 to 5 for each participant. These scores represented the participant's subjective assessment of the acoustic clarity of the room, with a score of 1 corresponding to the minimum perceived clarity and a score of 5 corresponding to the maximum perceived clarity. As responses were limited to fixed ordinal positions on the scale, the resulting data were integers representing categorical rankings.
A hypothesis testing approach known as the Cochran-Mantel-Haenszel (CMH) test was used for statistical analysis [22, 23]. This method facilitates the evaluation of associations between two or more categorical variables while controlling for potential confounding factors. Although the CMH test is commonly used in disciplines such as epidemiology and clinical trials, its application in the field of acoustics is relatively low [13, 24].
Originally, the CMH test was designed to examine how a variable K affects the relationship between two dichotomous variables, X and Y. However, its formulation has since been generalized to study experiments in which X and Y are not dichotomous.
The first step in the analysis is to create a contingency table for each value of the variable K. These tables are used to show how often each combination of responses occurred. In this study, X is the perceived clarity rating given by the participants and Y is the level of the acoustic parameter C_{80} derived from the impulse responses used to generate the stimuli of the test. As each participant rated five different musical motifs, one table was created for each, making a total of five. The size of the final table is 5x6x5. Each cell in the table shows how many participants gave a particular clarity rating when listening to a specific C_{80} level for a given musical piece.
The CMH analysis requires every row and column in the table to add up to more than zero. In the test, some clarity ratings were never selected for certain combinations of musical motifs and levels of C_{80}, which does not meet the requirements of the CMH analysis. To correct this, a method was applied to simplify the clarity ratings into three broader levels [25]: *"not at all high"* and *"slightly high"* were combined into a low clarity level, *"moderately high"* became the medium clarity level, and *"very high"* and *"extremely high"* were combined into the high clarity level. This change reduced the table from a 5x6x5 layout to a 3x6x5 layout.
The CMH test returns two results for each table: a chi-squared value (χ^2) and a p-value. These indicate whether the differences between the clarity ratings are statistically significant. The value of χ^2 increases the more the ratings differ between the groups. In the case of the p-value, the greater the differences, the lower the value. We considered the results to be statistically significant if the p-value is lower than 0.05.

4. RESULTS AND DISCUSSION

The purpose of the CMH analyzes was to investigate the effect of musical training on the perception of acoustic clarity. The results of all the CMH tests conducted are summarized in Tab. 1, which reports the statistic χ^2 and the p-values. These values reflect the ability of each group of participants to discriminate changes in clarity between the six C_{80} levels and five musical motifs. The results are discussed separately for participants with and without formal musical training, followed by a qualitative evaluation of the perceptual performance of both groups.
The results show that musically trained participants consistently detected changes in C_{80} level across all stimuli evaluated. This suggests that, regardless of the specific musical motif, trained listeners were able to detect variations in clarity. Among the motifs, MM3 - characterized by a slow *tempo*, long notes, and *legato* articulation - returns the highest p-value, which was close to the threshold for statistical significance. The musical characteristics of the excerpt are likely to have reduced the perceptibility of variations in clarity, as the simplicity of its melodic and harmonic content may allow the musical structure to be perceived independently of the acoustic conditions. However, despite the relatively higher p-value, the result for MM3 remains statistically significant, confirming the ability of trained participants to discriminate differences in clarity.
In contrast, listeners without musical training showed a significantly reduced sensitivity to changes in clarity. Of the five motifs, only MM4 produced a p-value below 0.05, indicating statistical significance. This motif consists of a segment of Hispanic chant sung by a five-voice choir and set to Latin lyrics. Although not Latin speakers, the participants are native Spanish speakers, and the phonetic similarity between the languages probably made the sound of the sung words familiar. The observed increase in perceived clarity with higher levels of C_{80} appears to indicate an improvement in phonemic intelligibility as the C_{80} level of the stimuli increases, facilitating a clearer perception of the text and contributing to the significant result.
The potential influence of the text of the piece on the perception of clarity is further supported by comparing the results of MM2 and MM4. Both motifs have similar musical characteristics (slow *tempo* and sustained melody), but MM2 is played on a cello. Despite assessing similar musical features and the same range of C_{80} levels, untrained listeners did not detect the changes in clarity for MM2. This contrast reinforces the idea that the presence of speech or familiar phonemes may improve clarity perception in non-musicians.

Table 1. Results of the CMH analyses performed to evaluate the ability to detect variations in the C_{80} level for both groups of participants.

Musical motif		Trained	Untrained
MM1	χ^2	57.010	8.274
	p-value	**<0.0001**	0.602
MM2	χ^2	52.045	15.210
	p-value	**<0.0001**	0.125
MM3	χ^2	18.556	11.065
	p-value	**0.046**	0.352
MM4	χ^2	52.231	28.031
	p-value	**<0.0001**	**0.002**
MM5	χ^2	26.280	5.396
	p-value	**0.003**	0.863

Following the individual analysis of each group, a comparative overview reveals a marked disparity in the ability of the two groups of participants to detect changes in clarity. As shown in Tab. 1, trained participants significantly outperformed untrained participants across all musical motifs. These results are consistent with previous studies on pitch discrimination [1–5], which have consistently shown that musicians have lower detection thresholds for tonal changes and auditory masking. The results of this study add to the general consensus that musical training is associated with superior auditory perceptual skills.
The C_{80} values used in the test ranged from -1.75 to 2.30 dB, which corresponds to the clarity range commonly recommended for classical music performance [26]. The group of trained participants consisted of people actively engaged in musical interpretation, often performing in environments with similar acoustic characteristics. Their exposure to these conditions, combined with a formal education that emphasizes the importance of acoustic awareness and adaptation in performance environments, probably contributed to their increased sensitivity to variation in clarity. In contrast, untrained participants, unfamiliar with such environments, lacked the perceptual training necessary to detect subtle changes in C_{80}, especially at

the higher end of the clarity spectrum.
To complement the perceptual data, the time taken by the participants to complete the listening test was also measured. On average, trained participants completed the task in 13 minutes, while untrained participants took approximately 19 minutes. Given that participants could listen to the stimuli as many times as they wanted before making a judgment, this difference in time suggests that non-trained listeners took more time to make perceptual decisions, possibly due to greater uncertainty. This further supports the conclusion that musical training facilitates more efficient and confident performance in complex auditory discrimination tasks.

5. CONCLUSIONS

The objective of this research was to determine whether the musical training of the listeners is a relevant factor in perceiving changes in the clarity of a stimulus. To this end, a listening test was conducted in which two groups of participants were tasked with indicating how high they perceived the clarity of a total of 30 stimuli. The first group comprised musicians with a minimum of ten years of experience in classical music, while the second group consisted of individuals with no formal musical training. The stimuli of the listening test were created by the convolution of six simulated impulse responses and five musical motifs. The range of C_{80} levels evaluated in the test varied between from -1.75 to 2.30 dB.
Following the collection of the listening test data, a series of CMH analyzes were performed. The results obtained demonstrate that, in general, those who had received musical training were significantly more proficient in detecting changes in clarity. In the clarity range evaluated, trained participants were able to detect changes in the level of clarity independently of the musical motif. In contrast, the results of the CMH analysis show that non-trained participants were unable to discern changes in the clarity of the stimuli evaluated.
The motif MM4 is the only one in which a significant p-value was obtained for untrained participants, which means that they were able to perceive changes in the level of clarity. This motif is unique in that it features a vocal part incorporating a Latin text, which is believed to have contributed to the differentiation of the changes in clarity. The phonemes of Latin and Spanish, the mother language of the participants, are similar, and it is thought that this may have assisted the untrained participants in detecting the changes in clarity, as they were able to notice the clarity of these syllables.
The results suggest that musical training has a significant impact on participants' auditory skills. This finding is consistent with the results of previous studies that used tonal discrimination tasks, which have repeatedly shown that musicians exhibit superior analytical listening abilities.
In subsequent publications, the results of additional listening tests, which assess a broader range of clarity, will be presented. These tests will evaluate the impact of music education on participant responses, using additional statistical analyzes in order to determine whether the differences between their analytical listening abilities are significant.

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