APPARENT ASYMMETRY IN DISCRIMINATING BETWEEN TWO CLOSELY SPACED PITCHES

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1 INTRODUCTION

During recent research into the causes of pitch drift in amateur choirs, an investigation was conducted of the pitch-discrimination abilities of approximately 150 choral singers from eleven UK-based choirs. A series of tests, comprising 22 tone pairs set around A_4 (440 Hz), were presented to the singers. In eighteen of the pairs, one tone differed in pitch from the other. The difference was between ±1 and ±48 cents. As a control, in the remaining four pairs the two tones did not differ in pitch. The principal objective of the investigation was to determine whether the pitch-discrimination abilities of the singers were related to their choirs' pitch drift, but insufficient responses from some choirs made this objective unrealizable. However, the investigation had an interesting outcome, which to date appears not to have been reported in the literature. Over a range of small differences in pitches the singers appeared better able to detect a difference when the second tone was lower than the first (i.e. flattened) than when the second tone was higher than the first (i.e. sharpened). This paper presents the development of the investigation and its results. A discussion of the unanticipated effect follows, including an examination of possible reasons for its occurrence.

2 PITCH DISCRIMINATION INVESTIGATION

2.1 Background

According to Carl Seashore[1] an average unselected group of adults are capable of recognizing a change in pitch of approximately 3 Hz at the then international pitch of A_4 of 435 Hz (1930s). This represents an ability to detect a change of pitch of approximately ±12 cents, based on the equal temperament musical scale. Thus, any change in pitch occurring within these bounds is unlikely to be noticed by an average listener. However, Seashore cites Stücker[2] who found that the discrimination of professional musicians at the Royal Opera in Vienna was such that the keenest of them could distinguish better than one cent. Even the least keen-eared could detect a four cents difference – a far better pitch discrimination ability than that of the general population. Seashore believed that these exceptional responses were due to people with extremely 'fine ears' having received a high order of training.

Kishon-Rabin et al.[3] compared professional musicians' and non-musicians' abilities to discriminate non-musical frequencies (i.e. tones that do not correspond to notes in the musical scale). Their tests used three groups of tones starting at 250, 1000 and 1500 Hz. Each tone group consisted of a pair of reference tones of the same pitch and a tone that was offset in pitch from the other two. The offset was one of twenty 0.5 Hz steps (giving a maximum offset of 10 Hz) for the 250 Hz group, and one of twenty 1 Hz steps (giving a maximum offset of 20 Hz) for the two other groups. Subjects were presented with tone groups, and in each tone group testing began with the largest offset tone. The subjects were asked to identify the offset tone amongst the three tones presented. Tests were repeated, with the offset being gradually reduced until a wrong answer was received. The offset was then increased until the response was correct and then reduced again. In this way a threshold of discrimination was finally achieved. Each tone group was repeated three times. The results revealed that the professional musicians performed better than the non-musicians but there was an overlap between the two where the best of the non-musicians were better than the poorest of the musicians. These findings agreed with those of Spiegel and Watson[4] who found that, of the non-musicians tested, half were in the same discriminatory range as the musicians. Further, by using professional instrumentalists from both contemporary and classical genres for their tests, Kishon-Rabin found that classical musicians performed better. Finally, they confirmed that their subjects' pitch discrimination improved with repeated testing, supporting the notion that training will improve pitch discrimination.

The view that training improves listening ability, which may in turn lead to improved pitch discrimination, appears in an unexpected result from research by Dance and Shearer[5] who, whilst testing the hearing acuity of music students on both entry and exit of a four-year period of music studies, noted an average improvement of approximately 9dB HL (decibels, Hearing Level). As their research used an automated screening audiometer generating five tones between 500 Hz and 8 kHz, which is essentially a listening test, an overall improvement in listening appeared to have been gained from the students' training. It would be interesting to know whether this improvement in listening skills is also associated with an improvement in pitch discrimination abilities that the students may have developed during their musical training.

Given the above findings, would a cohort of amateur choral singers demonstrate a better than average pitch discrimination ability? Furthermore, would this contribute to a reduction in pitch drift with their respective choirs? The following section describes an experiment to investigate the pitch discrimination abilities of these singers.

2.2 Development of the pitch discrimination tests

An online survey platform provided by *Surveygizmo*®, Colorado, USA, was used to deliver the pitch discrimination tests. This platform was selected since audio files could be incorporated into surveys on this platform – something not possible with other widely used survey platforms at the time of testing (2015). An online platform was chosen as it would have been impractical for the singers to participate in the tests either at a regular choir practice, due to insufficient time and equipment, or at the Open University's campus, as the singers were members of choirs situated around the United Kingdom. A series of pilot tests, described later, ensured that a participant's usual method of listening to sounds on a computer was good enough to achieve reliable results for this investigation. Complete anonymity of participants was ensured, and no individual results were given.

Following an introduction and familiarization with the testing method, including the participants setting a comfortable listening level – which was not to be altered during the tests – participants were presented with 22 tone pairs in a random order. For each tone pair the participant was asked to decide whether the pitch of the second tone was the same as that of the first tone or different. In Seashore's tests, the second tone was always higher than the first but here, if different, the second tone was either lowered or raised at random. The tone pair could be listened to as many times as required, but a response had to be given before moving to the next pair of tones.

The first tone of each pair was always A_4, and the variation of the second tone from the first was between ±1 cent and ±48 cents – a positive value indicating a raised or sharpened tone, and a negative value indicating a lowered or flattened tone. All tones were sine waves. Table 1 lists the frequencies used along with the corresponding difference from A_4 in cents. The participants were asked not to take the tests more than once. (Although retakes were possible, they could be identified and deleted.) They were told that the sequence of tone pairs was random and changed each time the tests were taken. Randomization was intended to thwart participants from the same choir who compared results, and participants who retook the tests hoping to have learned from the previous attempt.

Each tone was two-seconds in duration and was generated as an individual 16-bit uncompressed two-channel (stereo) sound file with a 44.1 kHz sampling rate. A tone-generator algorithm, written for *Matlab*® from The Mathworks Inc., was used to generate each tone. Individual tones were then paired with the reference tone, A_4 (440 Hz), using *Audition CS6* from Adobe Inc. A period of 0.2 seconds of silence was added at the beginning, between, and at the end of the tone pairs. Cosine S-curve fading was applied at the beginning and end of each tone and the amplitude normalized to –3 dB. Twenty-two sound files, 18 with different tone pairs plus four pairs with identical tones, were generated. Each tone pair was given a random filename and uploaded to the prepared online survey platform. Initially, uncompressed files were used but, following the pilot tests described below, compressed MP3 files, with a 192 kb/s bitrate, were employed. This gave a seven-fold decrease in the file-size so reducing the download time, which was particularly noticeable at home locations.

Table 1 Tone frequencies and corresponding variations in cents used for the pitch discrimination tests (a negative cent-value implies a flattened tone)

No.	Frequency (Hz)	Variation from A_4 (cents)
1	427.968177	−48
2	431.941776	−32
3	434.946169	−20
4	435.952270	−16
5	436.960698	−12
6	437.971459	−8
7	438.984558	−4
8	439.491986	−2
9	439.745920	−1
10	**440.000000**	**0**
11	440.254228	1
12	440.508602	2
13	441.017792	4
14	442.037937	8
15	443.060442	12
16	444.085313	16
17	445.112554	20
18	448.208556	32
19	452.370084	48

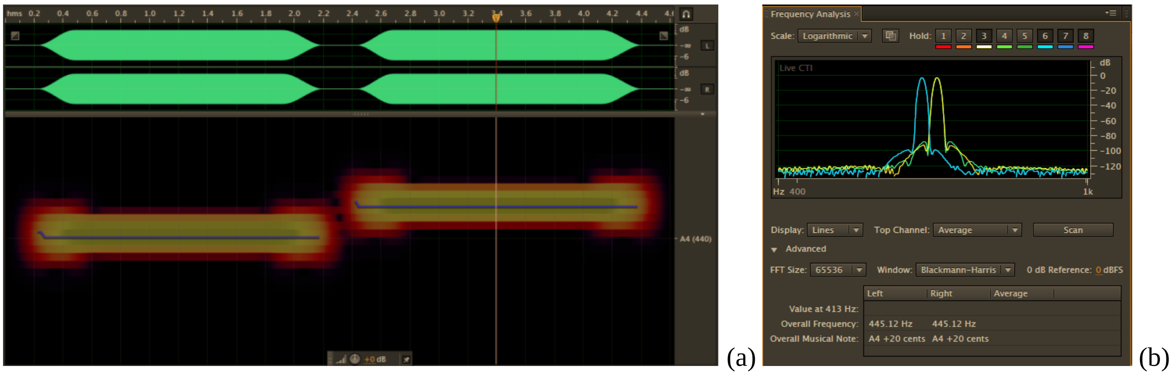

Figure 1 (a) Waveform and spectral pitch display of a sound file with the second tone raised by 20 cents; (b) frequency analysis showing the pitches of both tones, A_4 (light-blue) and A_4 +20 cents (pale-yellow) (displays from *Audition*)

2.3 Piloting the investigation

To ensure that, as far as possible, the varying locations and computing equipment of participants did not significantly affect the test results, a number of pilot tests were made with the cooperation of colleagues from the Open University. Each participant was required to take the test twice. Initially, they took the test using the same audio/computer facility on the university's campus. Each participant then re-took the test in their usual home or work environment (their choice). To reduce any effects of training from the first test, the order of the tone-pairs was randomized for the second test. The two sets of results were then compared to determine whether the change of location had produced any significant variations to the participant's answers. The opportunity was also taken to gather feedback from colleagues on the testing methods. This resulted in minor modifications to the descriptive text, along with the change to the file type referred to above, before releasing the tests to the choirs.

2.4 Running the pitch discrimination investigation with choirs

The pitch discrimination tests described above were part of an Open University PhD research project: *Pitch drift in* a cappella *choral singing*. This study, which involved the participation of eleven choirs with a total of up to 307 singers, offered an excellent opportunity to undertake research into pitch drift, including an investigation into whether singers have better than average pitch discrimination abilities. The pitch discrimination investigation was run on a per choir basis – each choir having a unique URL and password for the tests. Singers in each choir received an invitation to participate, which included the URL and password for their choir's pitch-discrimination tests. No personal information was requested apart from participants' voice type (soprano, alto, tenor or bass), which participants could decline to supply.

3 RESULTS

The results for each choir were downloaded from the investigation's website in a comma separated value (CSV) format and saved in a standard *Excel* workbook format. Ultimately, 154 singers (50.8%) took part, which was slightly disappointing but was possibly attributable to the need to access the tests from an online computer, something that not all singers were able to do. There may also have been a reluctance to take part given that the need for anonymity meant that the results could not be made known to the respondents. Interestingly, there was a large disparity between the numbers of responses from individual choirs; one choir returned a 77% response whilst in another only 20% of the singers took part. All the musical directors had been asked to encourage their singers to take part – perhaps some stressed the importance of the investigation more than others.

Of the 154 responses, seven were excluded as they appeared not to provide considered answers, in that the same response was given to all the tests and the voice type was not declared. This gave a final total of 147 responses, i.e. 48.5% of all singers. Analysis of the results gave a mean score of correct answers as 64.5% with a standard deviation of 11.1%, as shown in Figure 2.

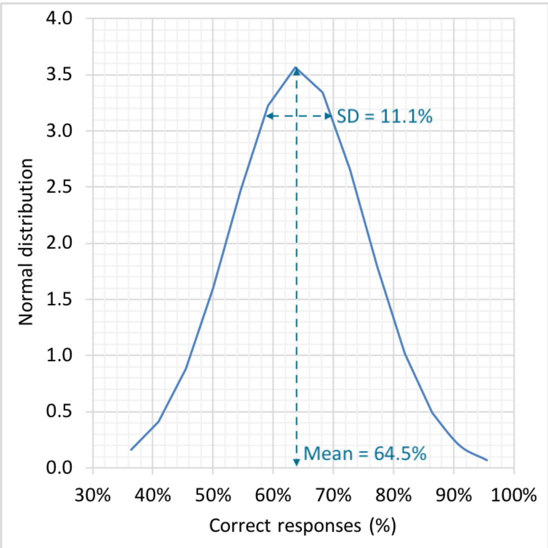

Figure 2 Percentage, mean and SD of correct responses for all participants (*n* = 147)

The percentages of correct answers to each tone pair are shown for all 147 participants in Figure 3. Note that the four equal tone pairs (i.e. with no pitch difference) are shown in the centre of the figure. The same colour and shading has been used for equal but opposite tone pairs to make comparisons easier to observe.

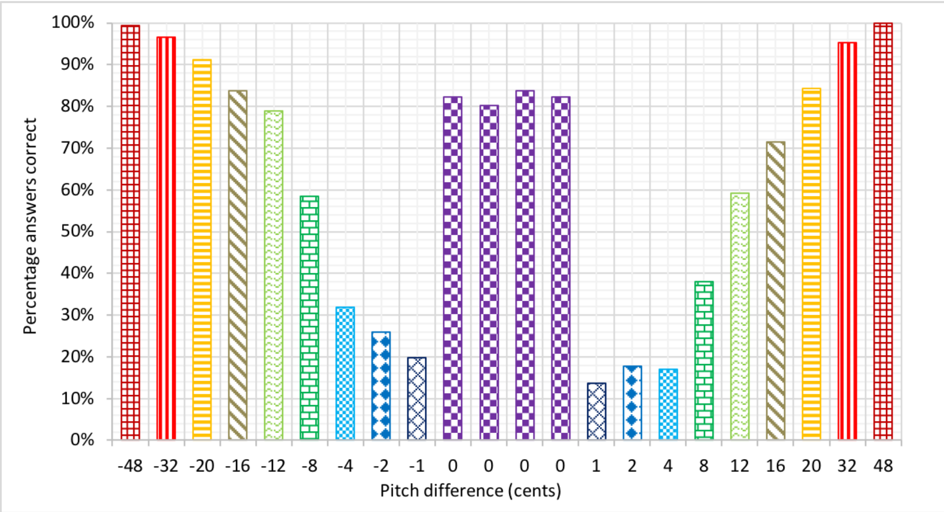

Figure 3 Percentage of correct answers of all participants for all 22 tone pairs (*n* = 147)

As would be expected, large differences in pitch between the tone pairs were correctly recognized, with an occasional incorrect response presumed to be an unforced error when selecting the answer. As the difference between pitches narrowed fewer correct responses were given and they fell below 20% when the second pitch was raised by 4 cents or less. However, it may be seen that when the second pitch was lowered by 4 cents the correct responses were above 30%, only falling to below 20% when the pitch difference was lowered by 1 cent.

This difference between the raised and lowered tone pairs is shown in detail in Figure 4. This figure demonstrates the difficulties experienced by many participants in perceiving small differences between tones and also when the two tones were equal. The percentage of correct responses for the tone pairs with differences of 8 cents and below are compared with the *incorrect responses* for the equal tone pairs.

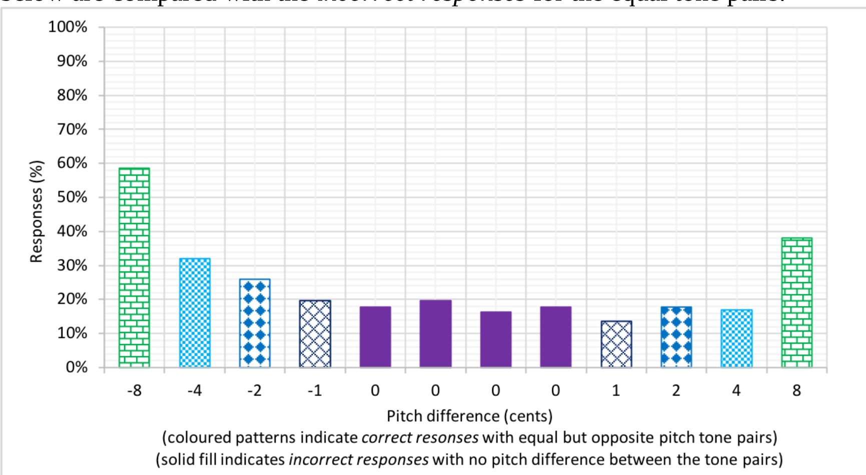

Figure 4 Detailed comparison of correct responses for small differences in tone pairs (patterned) compared with *incorrect responses* for equal tone pairs (solid) (*n* = 147)

Figure 4 shows that approximately 80% of the participants were unable to perceive any difference between tones that differed between –1 cent and +4 cents including where there was no difference between the two tones. However, it may be observed that although 38% of the participants were able to recognize the difference of +8 cents, 58% of the participants correctly identified a difference of –8 cents. This indicates over half the participants were better able to recognize a difference between two tones when the second tone was lowered (i.e. flattened) compared with when it was raised (i.e. sharpened). Furthermore, when the responses are plotted across the complete range of tone differences, as shown in Figure 5, it may be seen that the observation that participants are better able to recognize flattened tones is maintained across the complete range of tone differences of 32 cents and below.

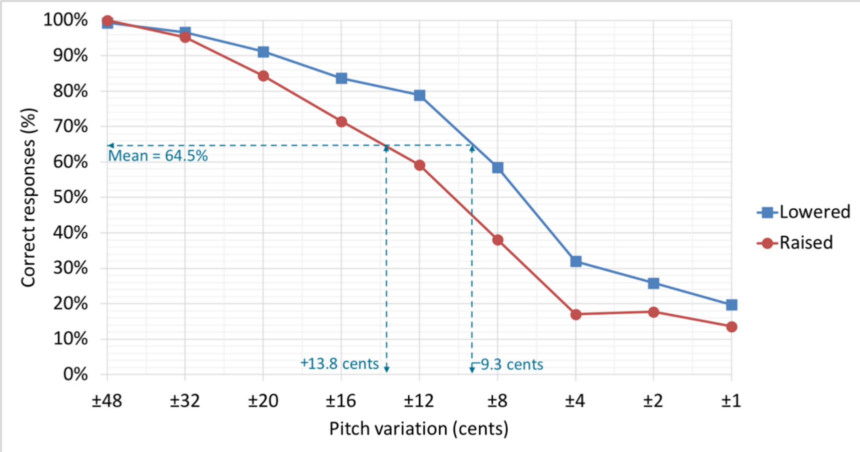

Figure 5 Correct results when the second tone is raised against when it is lowered (*n* = 147)

The square points in Figure 5 indicate the percentage of correct responses of the singers when the second tone was lowered in pitch. The round points indicate the correct responses when the pitch of the second tone was raised. (The first tone was the same in all cases.) The horizontal dotted line in the figure is set at the mean level of the correct responses of 64.5%, taken from Figure 2. This indicates that respondents would, on average, be able to discriminate between two tones when the second tone is lowered by approximately 9 cents, whereas they would only be able to discriminate between two tones when the second tone is raised by approximately 14 cents. The average of these two discrimination levels is 11.6 cents, which compares very favourably with the average of 12 cents found by Seashore (1938). However, Seashore made no mention of these differences due to the direction of the second tone, as reported here, as he did not consider it necessary to test lowering the second tone as well as raising it.

4 DISCUSSION

The results of this investigation demonstrate singers have average pitch discrimination abilities. However, they appear to be more discerning when the second pitch is lowered than when it is raised This is particularly noticeable when the difference between the tones is in the range of ±4 to ±20 cents. The results below ±4 cents are discounted as they are not substantially different to the responses when the two tones were the same (see Figure 4), indicating that participants were experiencing significant difficulties in recognizing whether changes were present or not when the tone pair differences were less than 4 cents.

Why should there be this asymmetry in the pitch discrimination abilities? Singers tend to pitch under the note (i.e. flat) and amateur choirs singing unaccompanied Western choral music are more likely to drift down in pitch (Seaton, et al.[6]) despite this result indicating that there appears to be better discernment for flattened rather than sharpened tones.

The range of frequencies covered by the tests varied between 427.96 Hz and 452.37 Hz. When set to normal room listening levels of around 80 dB SPL, the ear’s response between these two frequencies is reasonably flat, as shown in the ISO 226:2003[7] equal loudness contours and the Fletcher-Munson curves of Figure 6. The slight change should make little difference to the perception of the tone differences and recall that participants were instructed not to vary the listening level during the tests.

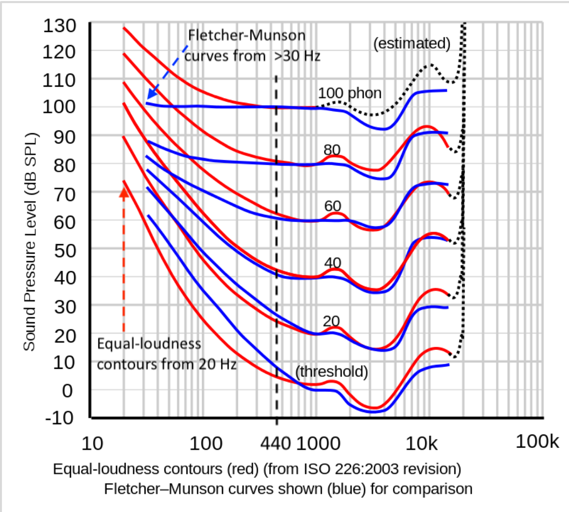

Figure 6 ISO 226:2003 equal loudness contours and Fletcher-Munson curves with the response at 440 Hz (A_4) shown as a dashed line

To confirm that the location used when taking the tests made no difference to this outcome, the results from the two locations used in the pilot tests were compared. Figure 7(a) shows the correct responses from the controlled location and Figure 7(b) from the individuals' locations. Although only 10 participants took part there was little difference between the results in the two locations. The lowered tone is better discerned (mostly) in both the controlled (a) and the participants' locations (b).

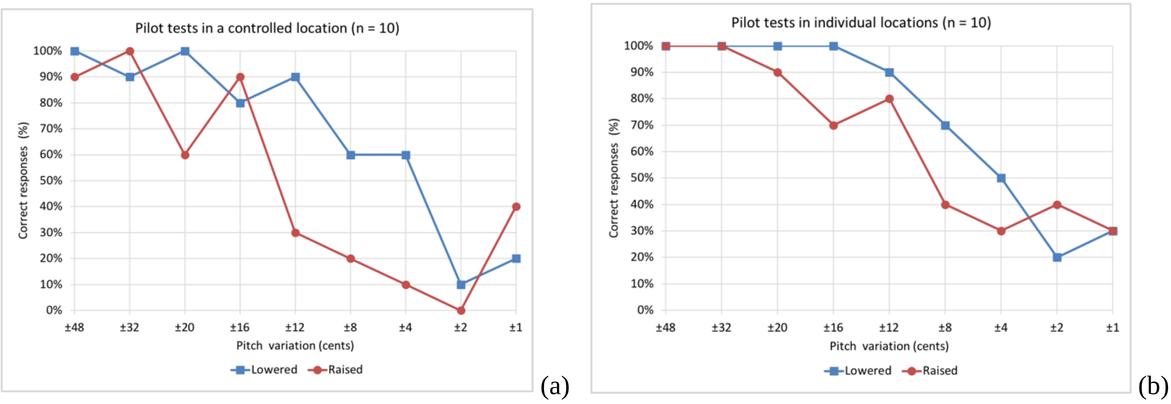

Figure 7 Results of the pilot tests for (a) controlled location; (b) individual locations (n = 10)

Murray[8] describes a curious phenomenon where 'the ability of the brain's hemispheres to discriminate small changes in pitch is differentially affected by the direction of the change'. Note that the right hemisphere processes sounds from the left ear, whilst sounds from the right ear are processed in the left hemisphere[9]. She reported that, with both musically sophisticated and naïve subjects, the right ear was better able to detect changes when the frequency changes were raised with the left ear appearing better able to detect lowered frequencies. Murray also suggests that the fact both hemispheres are involved in pitch perception demonstrates their importance in musical activities. She concludes by suggesting that 'music, like any complex activity is not a left or right brain activity exclusively but a whole brain adventure'.

In their discussion of the neurological aspects of musical performance, Marin and Perry[10] explain that during singing the auditory cortex in the right hemisphere is responsible for perceiving the sound of one's own voice. They suggest that this may be controlling the sung pitch and matching it to the intended pitch through auditory feedback. Whilst they make no suggestion that the right hemisphere is more proficient at pitch perception than the left, there may be a case to be made that, given the right hemisphere's ability to recognize a lowering in pitch, the right hemisphere is more discerning, which supports the results reported in this paper.

5 CONCLUSION

This paper introduces an unexpected outcome resulting from a pitch discrimination investigation of choral singers in amateur choirs. No published work has so far been found describing the asymmetric perception of small pure tone differences under ±32 cents, as reported here, bearing in mind that the participants were only asked to judge whether or not there was a pitch difference between the two tones in the pair, not the direction of the difference – i.e. raised or lowered. Further research, using different combinations and pitches of tone pairs, is ongoing to ensure that this asymmetry in the perception of tone differences is a genuine phenomenon and not an unintended consequence of the particular experimental methods used for the investigation.

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