Is Intrinsic Pitch language-dependent?

Evidences from a cross-linguistic vowel pitch experiment (with additional screening of the listeners dl for music and speech

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Abstract

Intrinsic Pitch differences (perceived pitch differences between high vs. low vowels) were found for Germanic languages. Our previous results gave evidence for a strong cross-linguistic difference when examining non-Germanic languages. We therefore designed a cross-linguistic vowel pitch discrimination experiment to examine the existence of intrinsic pitch in non-Germanic languages in comparison to Germanic languages. The experiment was conducted seperately with two groups of listeners: professional musicians and listeners who did not play an instrument at all. In a pre-experiment we screened the difference limen (dl) for the pitch discrimination of (1) musical stimuli and (2) speech stimuli. The reason was to screen the listeners' ability to successfully manage the following vowel pitch discrimination experiments and to allow listeners to train to identify pitch differences, which facilitates the following experiment.

Results for German listeners indicate intrinsic pitch differences corresponding to values given in literature. However, when examining groups differing in musical education it was found that intrinsic pitch is a weak phenomenon, with no significant results for the professional musicians. Results for Italian listeners show no pitch bias at all, indicating that intrinsic pitch is not present in this Romance language. We therefore give first evidence to the presented hypothesis that intrinsic pitch has to be classified as a language-specific phenomenon: It is assumed that the cue F0 is not used to classify vowel quality differences in the examined Romance languages.

1. Introduction

It is generally acknowledged that the pitch of high vowels is perceived lower compared to the pitch of low vowels, given that the vowels are presented with the same fundamental frequency (the pitch bias between the vowels is called intrinsic pitch). However, explanations for this perceptual phenomenon vary widely, three are summarized here:

- Purely psychoacoustic explanation: Stoll [1] attributed the pitch differences to the spectral properties of the vowels. He introduced the term "virtual pitch": it can be defined as a pitch value which depends on the pitch sensations of all different harmonics. Some harmonics could introduce small but significant pitch changes, shifting the overall perceived pitch of the stimulus slightly apart from the nominal fundamental frequency, which is the benchmark often associated with perceived pitch. His experiments strengthened a psychoacoustically derived explanation for intrinsic pitch, at least for the used synthetic vowels. However, the results in Pape et al. [2], in which the stimuli were normalized according to "virtual pitch" differences, showed nevertheless intrinsic pitch differences, therefore our results disconfirm the theory given by Stoll.
- Fowler and Brown [3] hypothesize that intrinsic pitch could be seen as a compensation for intrinsic fundamental frequency differences (IF0). IF0 describes the speech production differences between high and low vowels, which range around 10-15Hz. The phenomenon was found in all major language families, independent of their vowel inventory ([4]). Fowler and Brown argue that a compensation on the perceptual side for IF0 could be necessary to avoid disturbances of the complete prosodic system: Assuming a pitch target is reached by the speaker, the prosodic system of the listener would be confused by the varying value of this pitch target due to vowels differing in height (and consequently in intrinsic pitch). However, their experimental data showed a magnitude of intrinsic pitch of only 1/10 of the magnitude of IF0, therefore IFO is, if at all, only partly compensated.
- According to Traunmüller ([5]) IF0 could be seen as an enhancement strategy. He found a strong dependence of the perceived openness of a vowel on the frequency distance of the F0-F1 value. So it seems that the perceptual system uses this distance to extract vowel quality information to enhance perceptual discriminability. However, to our knowledge Traunmüller gives no explanation for intrinsic pitch.

The above described studies have in common that they do not take into account effects due to the listener's native language. Following Fowler and Brown, the magnitude of intrinsic pitch should be equal in all languages using fundamental frequency prosodically. The same holds true for Stoll, since psychoacoustic principles are universal and should therefore apply to all languages. An important point is that the musical education of the listener was not controlled in these experiments. However, it is known (see i.e. [6], [7]) that pitch perception and discrimination accuracy is strongly dependent on the level of musical education of the listener.

Taking into account all these facts, the aim of the current study was to design a cross-linguistic pitch perception experiment to examine the following points, with regard to all relevant factors influencing pitch perception and discrimination of vowel pitch. Therefore we examined the following factors:

1. Difference limen (dl) of the listener: The pitch discrimination threshold (known as dl in literature) of each listener at a nominal male F0 (set to 120Hz) is screened to see if she is at all able to successfully manage the following pitch discrimination tasks. Preliminary experiments showed that some listeners seem to exhibit some kind of "pitch deafness". That means that they are not able to distinguish even large pitch differences. The reasons for this phenomenon are not clear, they are not assumed to be physical (at least to our knowledge no literature exists). A method is used so that the "higher/lower" dimension, which could cause problems for some listeners will be avoided. Due to the screening of the dl of the listener in the interesting frequency region it can be guaranteed that the listener is able to distinguish the pitch differences in the following experiments.

2. Dependence of intrinsic pitch on the native language: Is the phenomenon intrinsic pitch dependent on the native language of the listener? To our knowledge, up to now no experiments were conducted for listeners of Romance languages or tone languages. If intrinsic pitch is seen as a compensation for IF0 then it should also be present in these language, assumed that the language uses F0 prosodically. However, results in Pape et al. [2] speak for a dependency of intrinsic pitch on the native language, showing that intrinsic pitch was nearly not present in Catalan for the presented stimuli (which differed in roundedness and tenseness), whereas German listeners showed intrinsic pitch effects. Thus, in the present study we will test if intrinsic pitch is present in non-Germanic languages when examining vowels which differ maximally in openness, which should give therefore the maximal intrinsic pitch difference magnitude.

3. Dependence on the language source of the stimuli: It will be tested if intrinsic pitch is dependent on the identity of the stimuli: We found ([2]) that Catalan listeners were quite insensitive to the given pitch difference when judging vowels. An explanation could be the use of German stimuli for the experiment. Although up to our knowledge no results are known that pitch discrimination is dependent on the language of the presented stimuli it is possible that the "unusual" vowel quality of the non-native vowels presented a difficulty and source of perceptual disturbance and interference for the Catalan listeners. So in the present experiment intrinsic pitch will be examined with both (1) the German stimuli for each language to be examined and (2) stimuli from the native language of the listener, corresponding as close as possible to the German counterparts.

4. Dependence on musical education: The populations will be divided into musically educated listeners and musically uneducated listeners. For the musically educated listeners only listeners with an academic degree from a music conservatory (mostly professional musicians) will be tested, therefore it could be guaranteed that they had a maximal amount of practice in aural training. As described, literature on intrinsic pitch did not control the musical education of the listeners. The reasons for testing two listener groups were to assess if intrinsic pitch is such a strong phenomenon that musically completely uneducated listeners would robustly show significant pitch differences, indicating a reliable linguistic component. In contrast, the results for the professional musicians would indicate if the effect and its amount would be the same for persons judging pitches everyday in their professional life. It is expected that musical education will have a strong influence on the magnitude and standard deviation of the intrinsic pitch differences with smaller magnitude and also smaller standard deviations for the musicians (hypothesis: because they should be able to judge the physical properties of the sound more accurately). Since both groups are apparently extreme groups concerning musical education, a German intermediate group consisting of amateur musicians were also recorded to allow for conclusions when faced with contrasting results for professionals and non-musicians.

2. Method

2.1. The stimuli

For all experiments, all stimuli consisted of natural sounds and vowels with a fundamental frequency of 120Hz. The length was normalized for all stimuli to 80ms, all stimuli were provided with linear ramps at the beginning and the end to avoid pitch smearing. All stimuli were normalized to a unique loudness to avoid pitch differences due to different loudness (see[8]).

A note on synthetic stimuli: Experiments with synthetic stimuli (both musical tones and vowels) in a pre-test all failed due to the artificial character. Most listeners did not accept these sounds as derived "from a musical instrument" or "spoken by a speaker". Therefore, since it cannot be controlled what the influence would be on linguistic pitch judgements and dl would be if the listener is judging "a strange sqeezing sound" which could interfere with her perceptual resources, we preferred natural sounds which would give a real world impression

The discrimination threshold experiment: The speech signal for the dl part of the experiment consisted of the native vowel /i/ (German vowel for the German listeners and Italian vowel for the Italian listeners).

The music tone consisted of a violine tone (lowest note) pitch shifted down to 120Hz (PSOLA, without formant correction). Different musical tones (natural and synthesized) were pre-tested to find the most suitable. The violin tone was rated as the most suitable since it sounded recognizably as coming from a musical instrument given the short duration.

The intrinsic pitch experiment: The vowels were the German vowels /i:/ and /a:/ in the first experiment for all listeners and additionally the Italian vowels /i/ and /a/ for the Italian listeners. All vowels were cut from a natural speech vowel in stressed position and in nasal context (to avoid disturbance of the formants and F0 due to contextual effects). In case that the length of the stable part of the vowel was too short, periods of the mid part of the vowel were doubled.

2.2. Procedure and signal path

The procedure for the dl measurements was 2I2AFC (**T**wo **I**nterval **T**wo **A**lternative **F**orced **C**hoice, which is a standard when examining dl in psychoacoustics, see ([9][10]). 2I2AFC was shown to be superior compared to other methods since it minimizes undesirable pitch memory effects but allows to avoid the higher/lower dimension (see [10] for a comparison of different methods). It picks the "odd one" out of four tones where three tones are equal and one is higher in pitch. Listeners could repeat the stimuli as often as necessary.

The procedure for the intrinsic pitch measurement was 2AFC with three runs 72 repetitions each. In each pair two different vowels had to be judged according to the task: "Which of the vowels, the first or the second, is higher in pitch?". The vowels were randomly paired (in both possible orders) with each possible different F0 value in the range +10Hz to –10Hz in 2.5Hz steps. The listeners could repeat each pair only once. The procedure was explained beforehand with written instructions and oral presentations to insure that the listener understood that the focus laid on the pitch judgement (and not a judgement according to the different timbre of the vowels).

The signal path consisted of a high quality DAC (Benchmark DAC1) fed into excellent headphones (Sennheiser HD600). The reasons for this choice were the attempt to avoid the typical low-level distortions in the (for pitch experiments most relevant) region around 200-500Hz.

2.3. The listeners

63 German listeners participated in the experiment, 10 professional musicians and 37 non-musicians (persons did not play a musical instrument). We also tested 16 amateur musicians as an intermediate group. The non-musicians were mostly students or graduates of different phonetics departments in Germany (Berlin, Munich, Kiel). The professional musicians were graduates from different music conservatories in Germany and had therefore extended practical knowledge in both pitch discrimination ("hearing classes") and fine-tuned musical experience (playing string ensembles). The intermediate group (amateur musicians) played different instruments between 3 years and 5 years, all with auditory education.

For the Italian listeners, 32 persons participated in the experiment, 13 professional musicians and 19 non-musicians. The non-musicians were students from the language department in Lecce (South Italy). The professional musicians were graduates from the music conservatory in Monopoly (South Italy). Strong attention was paid that the both the musicians and non-musicians were not educated in neither German and English to avoid possible L2 interference during their judgement of the German stimuli.

3. Results and Discussion

3.1. Difference in dl for musical tone and vowel

The mean and standard deviation of the difference limen for German and Italian (relative to an F0 of 120Hz), for the musical tone and the vowel, are given in table1.
Furthermore table1 gives these values split by musical proficiency. As can be seen, all values are generally lower for the German listeners: both collapsed over all listeners and computed seperately for different musical education.

Table1: Means (sd in brackets) for the dl values for listeners of German and Italian. The values are given absolutely, referring to 120Hz as the base F0. Data is given for (1) all listeners and (2) split by musical proficiency.

		dl music	*dl vowel*
German	All listeners	122.7 (3.2)	123.7 (3.6)
	Professional mus	121.2 (0.3)	122 (0.8)
	Non-musicians	123.7 (3.9)	123.6 (1.4)
	Amateur mus.	121.6 (1.0)	122.4 (0.8)
Italian	All listeners	126.6 (7.9)	127.4 (7.6)
	Professional mus	122.4 (0.9)	123.9 (2.4)
	Non-musicians	129.9 (9.7)	129.1 (8.3)

We computed a two-factorial univariate ANOVA with the factors language (German, Italian) and musical education (professionals, non-musicians). We found no interaction between the factors ($F(1,1)=8.582$, $p<0.832$), therefore we could interpret the main effects: Both were significant (dl vowel: language $F(1,1)=54,83$, $p<0.001$, musical education $F(1,1)=8.582$, $p<0.005$; dl music: language $F(1,1)=7.073$ $p<0.01$, musical education $F(1,1)=12.662$, $p<0.001$). Figure1 gives the interaction plots for both variables in the computed ANOVA.

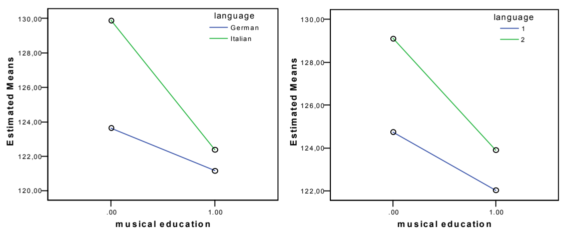

Figure1: Interaction plots of the factors language and musical education (0=non-musicians, 1=professionals). Shown in the left plane is the variable dl for the musical tone, at the right plane the dl for speech.

Following we examine closer the differences in language and musical education:

1. Differences between the languages (split by musical education): To see if differences were also significant when we compute the results split by musical education we computed a t-test with data split by musical proficiency. We found that both values for both groups (dl music and dl vowel at professionals and non-musicians) were significantly different between the languages (all at the 5 percent level). The reasons for the musical tone difference for professional musicians comparing the Italian and German listeners are not clear: Both professional groups were mostly string instrument players, so given the identity of musical tone and the same education in tuning the value should not be different. Rather, judging the same stimulus the responses should not differ significantly (a closer examinations of the histograms for the listeners did not reveal possible artefacts due to different distributions).

For the different value of the dl for the vowel comparing all groups, it can be hypothesized that the speech character of the stimulus is stronger than the pure psychoacoustic pitch perception, therefore language-dependent phenomena may clearly occur here.

2. Differences in dl in dependence on musical education in each language: Examining significant effects of musical education (professional musicians vs. non-educated listeners) on the dl values we found that both values were significantly different for the two groups in both languages (significance slightly missed for German dl vowel), with naturally lower values for the professional musicians (German: $p<0.001$ for dl music and $p<0.062$ for dl vowel; Italian: $p<0.004$ for dl music and $p<0.002$ for dl vowel). So this replicates results in litertature that extensive aural training facilitates pitch processing and pitch discrimination accuracy, independent of the language. Further, extensive training also facilitates the pitch discrimination accuracy for speech processing, which can be seen in the lower values for the vowel dl in both languages for the professional musicians. Therefore this group benefits in allday speech processing from the aural training provided in the music conservatory.

3.2. Evaluation of listerns' response patterns for the intrinsic pitch experiment

Only 44out of the 63 German and 22 out of the 38 Italian listeners showed a rising response pattern for the given vowel pitch discrimination task. A rising response pattern was defined if there was a clear difference between the –10Hz comparison region (showing a low response probability) and the +10Hz region (showing a high response probability), additionally with a clear intermediate response probability. In general it was expected that the listener would show a overall rise from –10Hz towards +10Hz.

It is not clear why some listeners were insensitive to the given pitch difference in the task. It should be noted that the difference to be judged equals 1.3 semitones. As described, due to the dl pre-test, all listeners were "physically" able to distinguish the vowel pitch in the given region, therefore this pitch insensitivity calls for another explanation.

Splitting the listeners by musical education it was found that all of the musical educated listeners (German professionals and amateurs, Italian professionals) showed the expected monotone rising response pattern. Therefore it seems that the inability to respond to the given pitch task is only found among listeners who do not play an instrument and are therefore more variable and unsure in their pitch judgements. However, it can be seen that the percentage of the listeners with rising response compared to all listeners is higher for German listeners (70% German, 58% Italian). Thus it is hypothesized that German listeners are in general more sensitive to vowel pitch differences.

3.3. Pitch bias between high and low vowels for the listeners with monotone rising response pattern

We used probit analysis to fit ogives to the curves of individual subjects for the listeners with rising response pattern. Our dependent measure was the F0 difference between the vowels to be examined at which, on the fitted ogive, subjects judged the high vowel higher on 50% of the opportunties. The corresponding F0 value defines the perceived pitch bias. A t-test was computed to examine if this value was significantly different from 0Hz (naturally 0Hz would indicate no measurable pitch shift). Table 1 gives the mean and significance values for the German and Italian listeners.

Table2: Means (sd in brackets) and significance values for listeners of German and Italian. Data are given for (1) all listeners and (2) split by musical proficiency (see text for details). Significant values are bold printed.For the Italian listeners both the results for the response to the German stimuli (G.S.) and the Italian stimuli (I.S.) are given.

		Mean /i:/ vs. /a:/	***Significance***
German	**All listeners**	**1.7 (3)**	**t(43)=3.697, p<0.001**
	Professional mus.	1.4 (3)	t(14)=1.739, p<0.104
	Non-musicians	**2.6 (3.4)**	**t(18)=3.306, p<0.04**
	Amateur mus.	0.5 (1.7)	t(9)=0.896, p<0.394
Italian	All listeners G.S. All listeners I.S.	0.8(2.5) -0.9 (2)	t(19)=1.5,p<0.15 t(19)=1.69,p<0.1
	Professional G.S. Professional I.S.	0 (2.1) 0.2 (1.6)	t(11)=0.2,p<0.88 t(9)=0.37,p<0.72
	Non-mus. G.S. Non-mus. I.S.	2 (2) -1 (2.6)	t(4)=2.3,p<0.082 t(5)=0.934,p<0.4

Collapsing the data for all German listeners (professional musicians, amateurs and non-musicians) it was found that /i:/ had to be significantly higher (by 1.7Hz) compared to /a:/ to sound equal in pitch. Therefore the results for the German listeners replicate the results of Fowler and Brown for the intrinsic pitch differences between high and low vowels in English, with the same small magnitude found by these authors.

For the Italian listeners, no significant pitch bias could be extracted, neither for their foreign language vowels (the German stimuli) nor for the Italian vowels (their native stimuli). The results for the Italian listeners indicate that the phenomenon of intrinsic pitch is not present in Italian, at least not significantly tested with our method.

Since to our knowledge no literature exist examining the phenomenon of intrinsic pitch in Romance languages our results speak for the fact that intrinsic pitch is a language-dependent phenomenon. Therefore the theory of Fowler and Brown has to be rejected, at least partly. Since no intrinsic pitch is measurable in Italian no prosodic compensation can be assumed for IF0, although IF0 is shown to be present in Italian. Why should intrinsic pitch exist as a compensation for IF0 in English and German but not in Italian? An explanation would be that Italian uses F0 as a prosodic cue and German as an additional cue for vowel openness (see results in

Traunmüller [5]). Therefore prosodic compensation of IF0 would not necessarily occur in Italian because Italian listeners do not relate f0 differences to vowel quality in a consistent manner. For verifying this hypotheses however, identification tests are necessary.

Furthermore, the results for Catalan listeners in a similar task ([2]) imply that most listeners (both musical educated and non-educated) showed an increased insensitivity to the given pitch differences in the task. However, in Spanish and Catalan it can be shown that F0 is used as a cue for stress in the same way as in English and in German (see Llisterri et al. [11]) for perceptual results on F0 in a stress identification experiment). Therefore, the results in [2] could be explained assuming that also in Spanish and Catalan F0 is not used as a vowel quality cue which results in an increased insensitivity to differences in vowels when the task is to judge the vowels according to a pitch dimension.

3.4. Differences: musicians vs. non-musicians in German

However, examining the pitch bias separately for professional musicians and non-musicians (which to our knowledge has not been done until now, the musical background of the listeners was not regarded), it can be seen in table2 that the significance level is only reached for the group of the non-musicians, whereas the musicians slightly failed to reach significance (professionals $p<0.062$; non-musicians $p<0.04$). Reasons for the weak effect of the intrinsic pitch phenomenon are not clear: As described we used extreme groups to test the phenomenon. Therefore it could be possible that the group of professional musicians is extremely sensitive to the given pitch differences, but due to its everyday work they do not judge the vowel pitch linguistically, but more like any other sound (i.e. like any other instrument). Two reasons would speak against this hypothesis: First, none of the musicians appeared to judge the vowel like sounds from an instrument, which was carefully screened and asked for each listener. Secondly, as can be seen in table2, also for the amateur musicians the pitch bias was not significant. Since the term extreme group clearly does not apply to the amateur musicans, there would be no clear reason why all musically educated listeners should judge the pitch of the vowels merely on an acoustic level and not on a linguistic level. So the only conclusion which can be drawn is that intrinsic pitch is not a very stable phenomenon. Furthermore, it is weaker when examining musically educated listeners.

Wiersma ([12]) examined the existence of intrinsic pitch for sung vowels with musically educated listeners in English and was not able to extract a significant pitch bias. However, she concluded that in sung speech intrinsic pitch has to be suppressed to avoid distortion of musical pitch in perception, although IF0 can be found to a small amount in sung speech (Grieffenberg [13]).

4. Conclusion

To conclude, strong language dependent differences have been found comparing German and Italian. It seems that both dl and intrinsic pitch differs between the languages.

Examining intrinsic pitch for German, it was found that it is a weak phenomenon, especially when examining groups differing in musical education. Musical education was found to be an important factor in our experiment, but was not regarded sufficiently until now in literature examining intrinsic pitch.

Examining the differences in intrinsic pitch cross-linguistically comparing German and Italian, it can be seen that intrinsic pitch is not at all present in the Romance language as tested with our setup. Additionally, taking into account the results in Pape et al. 2005 ([2]) there is further evidence that intrinsic pitch is also not used in Catalan, although the cue F0 is used similar to Germanic languages for stress.

So our approach is to see intrinsic pitch as a language-dependent phenomenon. Reasons for the absence of intrinsic pitch in these Romance languages are speculative: Due to the smaller vowel inventory the possibility exists that IF0 is not perceptually used in these languages to facilitate vowel quality classification (in comparison to Germanic lanugages with a more crowded vowel inventory). However, given the fact that F0 is at least in Catalan used for stress in a comparable way to Germanic languages, the increased insensitivity for the F0 differences in Romance languages is unclear and calls for further examination.

An interesting experiment would be to replicate the F0-F1 distance studies by Traunmüller [5] with listeners of a Romance language to see if F0 actually does not have an influence and therefore does not contribute to the openness perception of vowels, which could be assumed given the presented intrinsic pitch results for Catalan and Italian.

5. Outlook

Experiments in other Romance languages, tone languages and English will be conducted to examine the universality of intrinsic pitch for more different languages. Since (1) the psychoacoustic pitch-shift theory of Stoll was shown to not account for the found pitch bias and (2) it seems that the prosody compensation theory is questionable at least for Italian and Catalan since no pitch bias could be extracted, experiments in other Romance languages (which exhibit IF0) will show if perceptual compensation, and intrinsic pitch at all, does exist in these languages. Experiments in tone languages will show if a different response pattern can be extracted since in these languages IF0 differences were found quite consistently, although to a smaller amount compared to non-tone languages. As described, an important point would be the conduction of identification experiments examing a possible difference in the F0-F2 distance perception for Germanic vs. Romance languages.

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7. References

[1] Stoll, G., “Pitch of vowels: Experimental and theoretical investigation of its dependence on vowel quality”, *Speech Communication*, vol.3, pp. 137-150, 1984..

[2] Pape, D., Mooshammer, C., Fuchs, S. and Hoole, P., “Intrinsic pitch-differences between German vowels /i:/, /I/ and /y:/ in a cross-linguistic perception experiment”, *Proceedings of the ISCA workshop on plasticity in speech perception (PSP2005)*, London, UK, 2005.

[3] Fowler, C.A. and Brown, J.M., “Intrinsic f0 differences in spoken and sung vowels and their perception by listeners”, *Perception and Psychophysics*, vol.59, no.5, pp.729-738, 1997.

[4] Whalen, D.H. and Levitt, A.G., “The universality of intrinsic F0 of vowels”, *Journal of Phonetics*, vol.23, 349-366., 1995.

[5] Traunmüller, H., “Some aspects of the sound of speech sounds”, In: Schouten MEH (ed.) “*The Psychophysics of Speech Perception*”. Dordrecht: Martinus Nijhoff, 293-305, 1987.

[6] Kishon-Rabin, L., Amir, O., Vexler, Y. and Zaltz Y., “Pitch discrimination: Are professional musicians better than non-musicians?” *J Basic Clin Physiol Pharmacol*. vol.12, no.2(Suppl.), pp.125-43, 2001.

[7] Schon, D., Magne C. and Besson M. “The music of speech: Music training facilitates pitch processing in both music and language” *Psychophysiology, vol.*41, no.3, pp.341-349, 2004.

[8] Moore, B.C., “*An introduction to the psychology of hearing*”, Elsevier Books, Oxford, UK, 2003.

[9] Kärnbach, C. “Adaptive threshold estimation with unforced-choice tasks”, *Perception and Psychophysics*, 63, 1377-1388, 2001.

[10] Sek, A. and Moore, B.C.J., “Frequency discrimination as a function of frequency, measured in several ways” *Journal of the Acoustical society of America*, 97, No.4, 2479-2486, 1995.

[11] Llisterri, J.M., de la Mota C.R. and Ríos, A., “The role of F0 peaks in the identification of lexical stress in Spanish”, in Braun, A. and Masthoff, H.R. (eds) *Phonetics and its applications. Festschrift for Jens-Peter Köster on the occasion of his 60th birthday,* Stuttgart: Franz Steiner Verlag, 350-361, 2002.

[12] Wiersma, V., “Perception of vowel intrinsic pitch by muscally trained listeners”, Unpublished M.Sc. thesis at the Speech and Language Processing Institute, University of Edinburgh, UK, 2003.

[13] Grieffenberg M. and Reinholt-Petersen N., “The effect of high and low vowels on the fundamental frequency in singing: Some preliminary observations. (Annual Report), Institute of Phonetics, University of Copenhagen, 1982.