Congenital Amusia in linguistic and non-linguistic pitch perception: What behavior and reaction times reveal

Jasmin Pfeifer [1, 2], *Silke Hamann* [1], *Mats Exter* [2]

[1] Amsterdam Center for Language and Communication, University of Amsterdam, Amsterdam, The Netherlands

[2] Institute for Language and Information, Heinrich-Heine-University, Düsseldorf, Germany

J.Pfeifer@uva.nl, Silke.Hamann@uva.nl, exter@phil.hhu.de

Abstract

Congenital Amusia is a developmental disorder that has a negative influence on pitch perception. While it used to be described as a disorder of musical pitch perception, recent studies indicate that congenital amusics also show deficits in linguistic pitch perception.

This study investigates the perception of linguistic and non-linguistic pitch by ten German amusics and their matched controls. To test the influence of amusia on linguistic pitch perception, the present study parametrically varied pitch differences in steps of one semitone in resynthesized statement-question pairs. In addition, we looked at the influence of stimulus duration, continuity of pitch and direction of pitch change (statement or question). Performance accuracy and reaction times were recorded. Behavioral results show that amusics performed worse than controls over all conditions. The reaction time analysis supports these findings, as amusics were significantly slower across all conditions. Both groups were faster in discriminating statements than questions. Performance accuracy supports these findings, as questions were also harder to discriminate. The present results warrant further investigation of the linguistic factors influencing amusics' perception of intonation.

Index Terms: congenital amusia, pitch, perception disorder

1. Introduction

Congenital amusia is a lifelong disorder defined by difficulties with the perception of tonal differences in music as well as speech. Affected individuals (henceforth: *amusics*) are faced with impairments in the musical domain. Their symptoms can range from an inability to discriminate notes of different pitches, an inability to recognize well-known songs without lyrics or an inability to recognize out of tune singing to an inability to recognize music as such. In the most extreme cases, it causes extreme discomfort and headaches [1-3]. Insufficient exposure to music, a hearing deficiency or brain damage have been excluded as causes [4], while the exact underlying deficit is still unknown. A fine-grained pitch processing deficit has long been assumed as underlying cause [3-6] but has recently been rejected as the sole cause of congenital amusia [7, 8]. Other proposed underlying deficits are a learning disability with respect to statistical learning [9, 10], a working-memory deficit specific to non-verbal sequences [7, 11, 12] or problems with rapid auditory temporal processing [13]. There has been no conclusive evidence for any of these hypotheses and a combination of underlying deficits is now being considered [7].

While it has been proven that congenital amusia negatively affects the musical domain, there has been uncertainty whether it is domain-specific to music or whether it also affects language. It was presumed that language is spared since it employs bigger pitch differences [2, 4, 5] but there is mounting evidence proving that language is also affected [14-17]. Patel et al. ([14]) investigated the pitch perception of English and French speaking amusics with an AX discrimination task using natural statement-question pairs, edited in a way that they differed acoustically in the final region of the intonation contour only. Tonal analogs of these statement-question pairs were also used. They found that 30% of amusics had difficulty discriminating statements from questions and that they performed better for the tonal analogs.

Liu et al. ([15]) also investigated the pitch processing of amusics using an AX discrimination (same-different) task with statement–question pairs, nonsense speech and tonal analogs. As in the study by Patel et al. [14], the stimuli retained the final pitch of naturally produced statements or questions. In this study all amusics performed significantly worse across all three stimuli types. Furthermore, amusics performed better on gliding tones than on natural speech, thereby demonstrating that congenital amusia impairs intonation perception.

The above-mentioned studies thus indicate that the view of congenital amusia as a music-specific disorder has to be reconsidered. Further studies show that amusics have problems distinguishing subtle intonational differences [15], emotional prosody [18], and lexical tones in tonal languages [16, 17, 19, 20]. It is therefore justified to say that congenital amusia is not limited to the musical domain. In light of these findings, further investigations concerning amusics' impairments in language perception are in order.

The present study investigates congenital amusia in speakers of German, a group that has not previously been studied. Our goal is to amass more evidence that congenital amusia does negatively affect language, more specifically, intonation perception, and to investigate possible factors which might influence amusics' perception. This study examines the discrimination of linguistic pitch and two types of tonal analogs by ten amusics and 30 matched controls. In contrast to earlier studies [5, 14, 15], the present study employs a parametric manipulation of small pitch differences from one to seven semitones. Furthermore, it tests the influence of three parameters – the length of stimuli, the continuity of the pitch curve and the direction of pitch change – on amusics' perception. The influence of stimuli length – amusics perform worse for longer stimuli – was shown in studies proposing a memory deficit [11, 12]. The influence of the continuity of the pitch curve was shown to be relevant for amusics in an earlier study [16], and the influence of the direction of pitch change was indicated by a case study [2], the latter showing that the tested amusic only detected rising pitch changes. The present study did not only consider performance accuracy, but also reaction times since amusics have been shown to react more slowly than controls [8, 21, 22].

	Age	Gender	Years of education	MBEA scale	MBEA contour	MBEA interval	MBEA rhythm	MBEA average
Amusic								
Mean	30.7	8 F 2 M	16.1	22.0	20.5	20.4	22.6	21.4
SD	10.6		3.6	2.9	2.1	2.3	3.0	1.4
Control								
Mean	29.3	26 F 4 M	16.9	28.4	-	-	24.9	26.6
SD	9.6		2.8	1.2	-	-	2.9	1.7
t-test								
t	0.394		-0.686	-6.743			-2.109	-8.482
p	0.698		0.497	**< 0.001**			**0.042**	**< 0.001**

Table 1. *Subject characteristics. Descriptive statistics and results of t-tests comparing amusic and control participant characteristics and mean scores of both groups on subtests of the Montreal Battery of Evaluation of Amusia (MBEA). F: female; M: male; SD: standard deviation; t: test statistic of the independent samples t-test; p: probability value; bold face indicates significant results.*

2. Method

2.1. Participants

10 amusic participants and 30 matched control participants were included in this study. None had neurological or psychiatric disorders. All were German native speakers with normal hearing (defined as a mean hearing level of 20 dB or less in both ears), which was assessed before the experiment by pure tone audiometry at 250–8000 Hz. All participants were recruited via advertisement and screened with the *Montreal Battery of Evaluation of Amusia* (MBEA; [23]), the main diagnostic tool to assess amusics, which consists of six subtests testing melodic organization (scale, contour and interval subtests), temporal organization (rhythm and meter subtests) and melodic memory (memory subtest). A mean score of 22 (or lower) out of 30 on the first four subtests was used to diagnose amusia in the present study (cf. [13, 15] and [24] for a detailed discussion). In addition, participants also had to answer a questionnaire about their musical background. The control group was matched for age, handedness, gender and years of education (cf. Table 1). Controls were screened with a shortened version of the MBEA, which contained only the scale and the rhythm subtest, to assess their musical abilities. All participants received a small monetary reimbursement for their participation.

2.2. Stimuli

The experiment was conducted in German. A male native speaker read four statement-question pairs (with a mean fundamental frequency 106.6 Hz) that were embedded in a story. These productions were recorded in a sound-attenuated booth with a Sennheiser ME 62 microphone and a Sound Devices MixPre microphone preamplifier/mixer onto a Marantz PMD570 solid-state recorder with a sampling frequency of 44.1 kHz. The two sentences in each pair were lexically identical but differed in the final region in the direction of the intonation contour (cf. [14]), i.e. statements had a falling pitch and echo questions a rising one. The sentences were constructed so that they differed in two further phonetic parameters. The first parameter was the continuity of the pitch curve, i.e. half of the sentences consisted only of voiced sounds, resulting in a continuous pitch contour, while the other half contained voiceless obstruents, yielding a discontinuous pitch contour. The second parameter was length: half the sentences were short (sentences 1 to 4 had 3 to 6 syllables with a mean duration of 1.05 s and a SD of 0.08 s) and the other half long (sentences 5 to 8 had 7 to 10 syllables with a mean duration of 1.59 s and a SD of 0.24 s).

Praat [25] was utilized to extract, stylize and simplify the pitch contour of each target sentence (for details see [24]). The resulting simplified pitch contour was then used to replace the original pitch contour, yielding synthesized stimuli. Seven further pitch contours were created for every target sentence by moving the final pitch region of the stimulus either upwards (for the statements) or downwards (for the questions) in one-semitone steps, thereby yielding a set of eight different stimuli per target sentence (cf. Figure 1) and 64 stimuli in total. The question was manipulated downwards towards a statement, but never reached the pitch level of the recorded statement, and the statement was manipulated upwards. The logarithmic semitone scale was used instead of a linear scale (as e.g. in [5]), thereby making the result more comparable to pitch detection thresholds of amusics in the literature [3, 26].

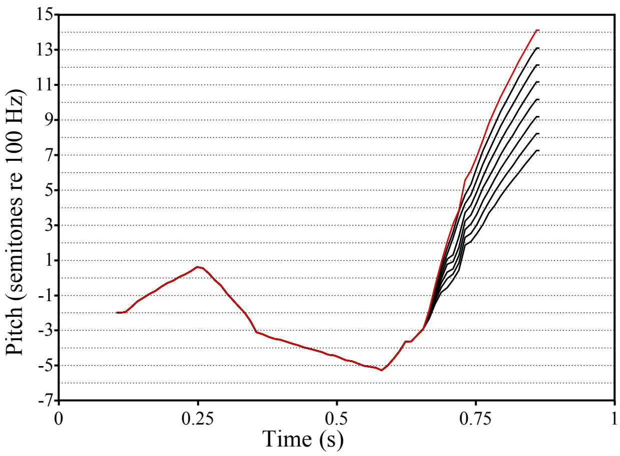

Figure 1. *Pitch contours of stimuli. Original simplified contour in red and seven manipulations in black.*

In addition to the speech stimuli, two types of tonal analogs, consisting of sinusoidal waves and pulse trains respectively, were created, resulting in a total of 192 different stimuli.

The sinusoidal wave analogs (short: sine) were created by converting the synthesized sentences into sinusoidal waves whose frequency exactly followed the sentences' pitch contour (cf. [14, 27]). The pulse train analogs (short: pulses) were created by converting the sine analogs into sequences of pulses, with the distance between pulses inversely proportional to the frequency of the pitch curve (a higher frequency corresponds to a smaller distance). These two types of tonal analogs were chosen since they differ in acoustic complexity. While the sinusoidal waves have a relatively simple acoustic signal, the pulse trains have a more complex acoustic signal. The three different stimulus types therefore vary in the presence or absence of linguistic material and in acoustic complexity from sine, as the simplest one, to pulses, as the intermediate one, to speech, as the most complex one.

Since an AX discrimination task was used, stimuli had to be paired. Each stimulus with an altered final pitch region (black in Figure 1) was once paired with itself and once with the unaltered version (red in Figure 1), while a separation between the stimuli created from different sentences and between the different stimulus types was maintained (i.e. sine was not mixed with pulse or speech stimuli etc.). This yielded seven 'different' pairs and one 'same' pair per stimulus. For counterbalancing reasons, an equal number of 'same' and 'different' pairs was included in the experiment, i.e. 14 stimuli pairs. In total, 336 experimental stimuli pairs were included, consisting of 8 original sentences (4 statement-question pairs) x 3 different stimulus types (speech stimuli and tonal analogs) x 14 stimuli pairs (7 'same' pairs with unaltered final pitch regions and 7 'different' pairs with altered final pitch regions). In addition to the 336 experimental trials, nine practice and 12 catch stimuli were created in the same way. Catch trials were 'different' stimuli pairs in which the final pitch region of one stimulus was altered by 24 semitones. These catch trials were included in the experiment to ensure participants paid attention and performed the task correctly. Controls and amusics perceived all catch pairs as different, thus no one had to be excluded on these grounds. Practice trials consisted of the three short, continuous, statement stimuli which were paired either with themselves (resulting in three 'same' stimuli pairs), or with contours that were raised finally by 2.5 and 5.5 semitones (resulting in six 'different" stimuli pairs). These nine practice trials were used in the practice session before the experiment.

2.3. Design and procedure

The 336 stimuli pairs differed in 5 conditions:

- type (voice, sine, pulses),
- length (short, long),
- continuity (continuous, discontinuous),
- direction (question, statement),
- interval (0-7 semitones).

They were used in a same-different discrimination task with a blocked design. The 14 stimuli pairs that shared all conditions were presented within a block in a randomized order. Across blocks, the order was pseudo-randomized so that blocks with more than two conditions in common did not immediately follow each other. The order of blocks was counter-balanced across participants to compensate for fatigue. There were two breaks, one after every eight blocks.

The experimental sessions took place in the phonetics laboratory at the University of Düsseldorf and lasted approximately 60 minutes. Participants were seated in a sound-attenuated booth, and the stimuli were presented over AKG K 601 headphones using Praat on a Windows XP computer. Participants could adjust the volume to a comfortable level. They were asked to listen carefully to each trial and to decide whether the two stimuli were the same or different. They were told to respond as quickly as possible by pressing labeled buttons on the keyboard. Behavioral results and reaction times were recorded with Praat.

Each trial followed the same pattern: A warning signal was followed by one second of silence followed by the stimulus pair with an inter-stimulus interval (ISI) of one second. This ISI was chosen since Williamson et al. [13] pointed out that longer ISIs may interfere with possible pitch memory deficits in amusics, while shorter ISIs might cause problems due to a rapid auditory processing deficit in amusics. The experiment was preceded by a practice session to familiarize participants with the experimental procedure, the different types of stimuli and the semitone intervals. Feedback was provided during the practice session but not during the experiment.

3. Results

Responses were scored as hits when different stimuli pairs were correctly identified as different, and as misses when they were not correctly identified. Conversely, correctly identified same-pairs were scored as correct rejections and as false alarms when they were incorrectly identified.

3.1. Reaction time (RT) analysis

RTs were measured from the offset of the second stimulus of each pair. Outliers, here defined as negative RTs or RTs slower than 3 SD of the group mean, were excluded. In a first step, the mean RTs for controls and amusics over all conditions were compared (cf. Figure 2). The RTs of amusics (M = 1121, SE = 13.2) and controls (M = 946, SE = 4.6) differed significantly ($t(998) = 12.5$, $p < 0.001$) only for hits. This represented a medium-sized effect $r = 0.37$. RTs are conventionally analyzed for hits only, therefore the following analysis takes only RTs of hits into account.

The next step consists of analyzing the RTs per variation step in semitones. Controls and amusics differed significantly at all semitone steps, except step 1 (Table 2). Next, RTs were submitted to an ANOVA with group (amusic, control) as the between-participant factor and length, continuity, direction and type as within-participant factors. All parameters had significant main effects except for continuity, which failed to reach significance ($p = 0.29$). Since continuity was also not included in any significant interactions, it was excluded from the statistical analysis in order to increase the power of the analysis. An ANOVA was run again without continuity.

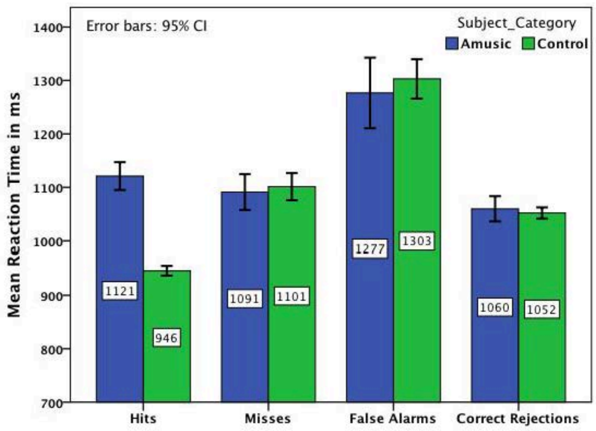

Figure 2. *Mean reaction times of amusics and controls for hits, misses, false alarms and correct rejections.*

A significant main effect was found for group ($F(1, 35) = 4.89$, $p = 0.034$), indicating that amusic participants were slower to respond than control participants.

Variation Step	1	2	3	4	5	6	7	average
Amusic								
Mean (in ms)	1215	1208	1115	1079	1142	1109	1090	1121
SD (in ms)	482	384	394	343	377	360	355	374
Control								
Mean (in ms)	1112	1035	982	936	915	901	885	946
SD (in ms)	336	305	320	280	273	268	244	290
t-test								
t	1.414	4.188	3.094	4.442	6.697	6.922	7.070	12.501
p	0.163	**< 0.001**	**0.002**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**

Table 2. *Descriptive statistics and results of t-tests comparing amusics' and controls' reaction times across variation steps; SD: standard deviation; t: test statistic of the independent samples t-test; p: probability value; bold face indicates significant results.*

Significant main effects were also found for: Length ($F(1, 35) = 11.70$, $p = 0.002$), indicating that the discrimination of long stimuli ($M = 1008$, $SE = 33.2$) was faster than of short stimuli ($M = 1048$, $SE = 31.7$); direction ($F(1, 35) = 50.81$, $p < 0.001$), indicating that the discrimination of statements ($M = 979$, SE 32.8) was faster than that of questions ($M = 1077$, $SE = 32.6$); and type ($F(2, 70) = 7.82$, $p = 0.001$), indicating that the discrimination of voice stimuli ($M = 997$, $SE = 33.5$) was faster than of pulses ($M = 1028$, $SE = 30.5$) or sine stimuli ($M = 1059$, $SE = 35.3$). This last main effect reflected the significant difference between voice and sine stimuli ($p < 0.001$). There were no significant interactions between group and any of the other parameters. The absence of any significant interactions with group shows that the investigated parameters influenced the reaction times of amusics and controls in the same way, while still maintaining the main effect of group, i.e. that amusics are generally slower. There was a significant interaction between length and direction but since this interaction does not involve a group difference, it is not analyzed further at this point.

3.2. Performance accuracy analysis

The hit rate was calculated by dividing the number of correct responses for different trials by the total number of different trials. Across all conditions, amusics ($M = 0.42$, $SD = 0.20$) and controls ($M = 0.80$, $SD = 0.23$) differed significantly ($t(12) = -3.35$, $p = 0.006$). An analysis using Signal Detection Theory, a psychophysical approach of measuring performance, while taking the individual's ability to discriminate and their response bias into consideration [28], was also conducted. All data were analyzed using a regression analysis. A detailed discussion of this analysis with a subset of the participants can be found in [24]. Due to lack of space, only the results of the hit rate analysis will be reported here briefly. Main effects of group ($p < 0.001$), direction ($p < 0.001$), type ($p < 0.001$) and interval ($p < 0.001$) were found and interactions between group and type ($p < 0.001$) and group and interval ($p < 0.001$) were also found.

4. Discussion

The present study amasses more evidence that congenital amusia negatively influences speech perception by showing that amusics performed behaviorally worse and slower than controls for non-linguistic as well as linguistic stimuli. This supports earlier studies [14-17] claiming that amusia is not limited to the musical domain. While Patel et al. [14] found that only a subset of amusics had an impaired discrimination of linguistic material, in the present study all amusics were impaired (cf. also [15]).

Furthermore different parameters influencing amusics' perception were considered. It was shown that even at a distance of seven semitones, amusics were still impaired in comparison to controls. Their hit rate was not only lower, their reaction times were also significantly slower (see also [8, 21, 22]). Continuity of the stimuli did not significantly influence perception even though amusics performed slower/worse for discontinuous stimuli, supporting the findings by [16] where amusics performed worse for discrete stimuli. Questions, i.e. rising pitch changes, were discriminated slower and worse by amusics and controls. This is in contrast to the findings of [2], where the one tested amusic could only detect rising pitch changes. We hypothesize that statements might have been easier to discriminate since they appear more often than questions in real speech.

There were also dissociations between reaction times and performance accuracy: For length, there was no influence on the performance accuracy, but on RTs: surprisingly, long stimuli were discriminated faster. And while amusic and controls performed faster for linguistic stimuli, controls performed significantly better for non-linguistic stimuli, which was not the case for amusics. Amusics' performance accuracy did not differ for linguistic and non-linguistic stimuli. This supports findings by [16], who also found that the presence or absence of linguistic material did not influence amusics' performance, while controls performed better for non-linguistic material. This dissociation between reaction times and performance accuracy as well as the influence of the pitch change direction need to be investigated further.

5. Conclusions

In the present study, we investigated the pitch perception of amusics. Our goal was to gather further evidence that amusia does indeed affect intonation perception and to gain insight into factors that might have an influence. We found that amusics performed significantly worse across the entire experiment. Their pitch perception was impaired for speech stimuli and tonal analogs even at a distance of seven semitones, which is in line with earlier studies ([14-17]). This further substantiates the hypothesis that congenital amusia is not domain-specific but rather a general perceptual impairment. Concerning possible factors influencing amusics' perception, stimuli length and direction of pitch change were shown to play a role while continuity of stimuli did not. These and other linguistic parameters require further investigation.

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