

# Perceptual magnet effect in German boundary tones

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## Abstract

The experiment described in this paper tests for the perceptual magnet effect within the categories of high and low boundary tones in German, referring to question and statement, respectively. The experiment is based on previous work in which the categoral status of the two German boundary tones had been evaluated. The results found there showed that there was a discrimination ability within categories which could not be explained by the classical definition of categoral perception. The results reported in the present paper show that a perceptual magnet exists in the statement category but not in the question category.

## 1. Introduction

Three essential phonetic cues are used for coding prosodic information: duration, intensity and fundamental frequency ( $F_0$ ). Pitch, i.e. perceived  $F_0$ , can express many functions such as tone and accent, intonational meaning and discourse structure [1]. But how can one single cue give rise to so many interpretations? How can speakers and listeners distinguish the different possibilities of interpretation?

This presentation focuses on a small part of the German intonation system: the perception of boundary tones. In a preceding experiment [2] categoral perception (CP) of low and high boundary tones in German, presented by “statement” and “question” respectively, was found, but some kind of discrimination ability within each category was also shown which is not in line with the strict definition of categoral perception. This result could be better explained by the concept of the perceptual magnet effect (PME) introduced by Kuhl [3]. The experiment presented in this paper was designed with its main focus on PME in the two categories examined, i.e. the category of the low (L%) and the high (H%) boundary tone. To test for PME we chose a sentence that was syntactically ambiguous between statement and question, the contrast being encoded by the phrase-final intonation. We created a series of stimuli which differed in the phrase-final  $F_0$  contour. The original intensity contour and the original timing were retained. For manipulation we used the ERB (Equivalent Rectangular Bandwidth) scale, because this frequency scale is considered to be the most satisfactory psychophysical transformation of pitch intervals in human speech [4].

## 2. Methods

### 2.1. Stimuli

In this experiment the same test sentence as in [2] was used: “Steht alles im Kochbuch” (“It’s all in the cookbook”). The sentence had been selected from a recording of several dialogs with

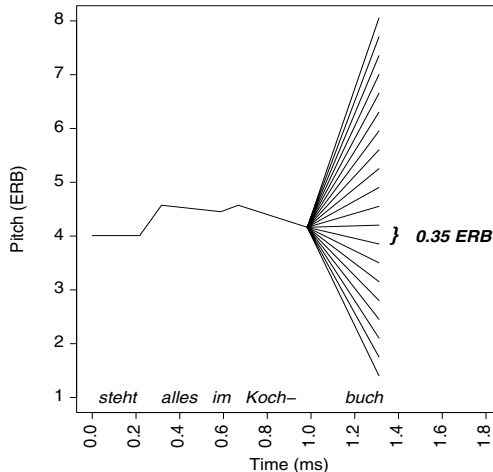


Figure 1: Set of 20 stimuli used in the PME tests, differing in the phrase-final  $F_0$  contour.

natural intonation. A professional male speaker of German read these dialogs in the anechoic chamber at the Institute of Natural Language Processing (IMS). The selected sentence satisfied the following conditions for manipulation: it was syntactically ambiguous between statement and question; and the sentence final syllable was unaccented, did not contain a schwa, and its  $F_0$  formed a plateau-like contour ending on medium level (128 Hz) within the speaker’s pitch range.

Averaged over all sentences produced by this speaker,  $F_0$  rises by 100 Hz to reach a typical H%, and falls by 50 Hz to reach a typical L%, which resulted in 228 Hz for H% and 78 Hz for L% in our test sentence. The 11-step continuum along the ERB scale with a step size of 0.35 ERB created for the CP experiment [2] was expanded to a 20-step continuum by producing stimuli with the same step size below and above the typical L% and H%, respectively. Further stimuli were produced as long as they sounded natural, which was evaluated by several listeners. In the new stimulus continuum the lowest boundary tone has an  $F_0$  value of 35.3 Hz and the highest boundary tone has an  $F_0$  value of 337.5 Hz. With this extension of the stimulus set we ensured that the presumed perceptual magnets of each boundary tone category were included. The  $F_0$  contours were resynthesized by means of PSOLA [5] and the stimuli were numbered from 1 (lowest boundary tone) to 20 (highest boundary tone). Figure 1 shows a schematic illustration of the manipulation.

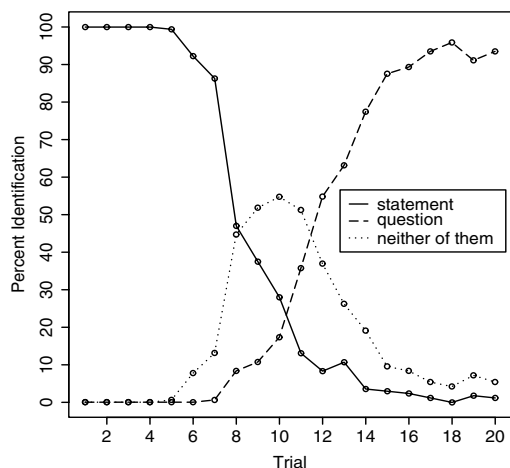


Figure 2: *Percent identification of all stimuli as a function of stimulus step number, averaged over listeners.*

## 2.2. Experimental procedures

Three subtests were created according to Kuhl [3] to test for the perceptual magnet effect, namely an identification test, a goodness rating task and a discrimination test. The tests had to be performed in this order because the results of the identification render the input stimuli for the goodness rating, and the results of the goodness rating render the input stimuli for the discrimination. Because of the high number of stimuli and because of the need to test both categories separately during the second and the third subtests, the subjects had to complete seven subtests in total (1 identification, 2 goodness ratings and 4 discriminations) with a break of at least one hour between any two subtests.

21 native German listeners, 10 males and 11 females, who were students or staff at the IMS, participated in the experiment on a voluntary basis. No subject reported any perceptual deficits. The experiment was performed individually. The subjects listened to the stimuli via headphones. The volume of the stimuli was set to a comfortable level at the beginning of each subtest. After listening to a stimulus the subjects had to choose one of the response alternatives before listening to the next one.

## 3. Experimental results

### 3.1. Identification

During identification listeners were asked to classify the stimuli as either *question* or *statement* or *neither question nor statement*. The third category should be used when the subject was not sure to which of the two main categories the stimulus belonged. There were 20 stimuli occurring 8 times each in the test in randomized order, i.e. subjects had to identify 160 stimuli in total.

The individual results diverge slightly. Most subjects used all three given categories and demonstrated that there are in fact cases in which they are unsure about the classification of the stimulus. Two subjects did not use the category *neither question nor statement*. They reported that they had always been sure to which category the stimulus belonged. As shown in Figure 2 the *statement* category was almost correctly identified and the *question* category was above 90%, whereas the category *nei-*

*ther question nor statement* had an identification rate of at most 55%. This seems to be counterevidence for the existence of a third category between the low and the high boundary tone in German, which was proposed in our previous paper [2]. Another observation is that the category *statement* has more constant identification rates within the category itself than the category *question*. This is in accordance with the fact that 4 subjects reported that they classified the stimuli 18 to 20 as belonging to the category *neither question nor statement* because these stimuli sounded unnatural, i.e. too high, for them.

Based on the results of the identification the two categories *statement* and *question* had to be isolated before starting the goodness rating task for each category. To ensure that only those stimuli are included in each of the two categories that are indeed members of the pertinent category, a stimulus was accepted for the goodness rating of its category if it was identified as a member of this category by more than 75% of the subjects. Two proportion tests verified that the stimuli 1 through 7 as well as the stimuli 14 through 20 did not differ significantly in their identification rates. According to these results the stimuli 1 through 7 and 14 through 20 were included in the goodness rating tasks for the categories *statement* and *question*, respectively.

### 3.2. Goodness rating

There were two goodness ratings, one for each category. The listeners were asked to label the quality of each stimulus within its category on a scale from 1 (*very bad exemplar of this category*) to 7 (*very good exemplar of this category*). Prior to both ratings there was a training session to acquaint the listeners with the range of the stimuli. There were 7 different stimuli within each category, labelled from A1 to A7 for *statement* and from F1 to F7 for *question*. They were repeated 10 times and presented in randomized order. This resulted in 70 stimuli for each goodness rating task.

For the *statement* category there were only slight individual differences in the rating of the stimuli. To get the prototype and the nonprototype for the *statement* category the stimulus with the highest and the stimulus with the lowest rating were calculated for each subject, resulting in two sets, one set of individual prototypes and the other of individual nonprototypes. The median of the first set corresponded to stimulus 2, i.e. this was the prototype of the *statement* category ( $P_S$ ), and the median of the second set corresponded to stimulus 7, i.e. this was the nonprototype of the *statement* category ( $NP_S$ ).

For the category *question* there were greater individual differences in the ratings of the stimuli than in the *statement* category. It was more difficult for all subjects to decide between good and not so good exemplars of this category than it was for the *statement* category. Four female subjects evaluated the highest stimuli as bad ones – they reported them to be unnaturally high – whereas all the other subjects rated these stimuli as the best ones. But as subjects had been asked to label the stimuli according to their individual impression, these four subjects were not excluded from further evaluation. The procedure to calculate the *question* prototype ( $P_Q$ ) and the *question* nonprototype ( $NP_Q$ ) was the same as for the *statement* category. For the category *question* the prototype corresponded to stimulus 6 and the nonprototype corresponded to stimulus 1. The difficulties in obtaining a clear prototype in the *question* category may be viewed as a first cue that there is no perceptual magnet in this category. This issue will be addressed in section 4 below.

### 3.3. Discrimination

In the discrimination test subjects listened to stimulus pairs that were either identical (AA) or different. In the latter case, the second stimulus was either higher (AB) or lower (BA) than the first one. One stimulus of each sentence pair was always either the prototype (P) or the nonprototype (NP), the other stimulus in the pair was one of the immediate neighbors of P or NP, respectively. The interstimulus interval within each pair was 500 ms [6] and each pair was repeated 7 times in the test. Discrimination was tested separately for each category. In addition there were two different test designs: first, the random design, in which the pairs including the prototype and those including the nonprototype were randomly mixed; second, the block design in which the pairs including P were tested separately from those including NP. Moreover, two subdesigns arose from the possibility that the order of presentation of these two blocks might affect the discrimination results, namely the P-first and the NP-first design. Every design included 126 different and 126 identical stimulus pairs for each category. Each subject participated in only one subdesign; the assignment of subjects was decided randomly. Because the number of stimuli was too large for one test session for each category, discrimination was split up into two tests for the *statement* and two tests for the *question* category. Again, a training session before each subtest served for the subjects to become acquainted with the stimuli and the differences within the pairs. During training listeners received feedback for their answers, but not during the test.

#### 3.3.1. Signal Detection Theory

Although the discrimination task involved different test designs, no order of presentation effect was found in the results. However, results of the individual subjects differed not only in their hit rates, i.e. how many pairs they correctly recognized as including different stimuli, but also in their false alarm rates, i.e. how many pairs they wrongly recognized as including different stimuli. This is in line with Signal Detection Theory (SDT) [7, 8]. According to SDT, listeners who share the same perceptual pre-condition (identical auditory threshold) can produce different results in a perception test because they use *response criteria* of different sizes. On any trial, the answer of the observer is YES if the evidence for the signal is larger than some value known as the *response criterion*, and NO when it is smaller than this value. Therefore the number of hits and false alarms depends on this criterion, known as  $\lambda_{Center}$ . For the description of the results we therefore have to take into account, first, the hit rate ( $h$ ), i.e. the number of hits against the total number of really different stimulus pairs, second, the false alarm rate ( $f$ ), i.e. the number of false alarms against the total number of really identical stimulus pairs, and third,  $\lambda_{Center}$  with  $\lambda_{Center} = (-f) - 0.5 * (h - f)$  [7].

#### 3.3.2. Statement category

For the category *statement* the hit rates of the stimuli in the immediate vicinity of the prototype  $P_S$  differ significantly in their mean values from those in the immediate vicinity of the nonprototype  $NP_S$ : there are significantly more hits in the  $NP_S$  environment. Concerning  $\lambda_{Center}$  there is also a significant difference between the  $P_S$  and the  $NP_S$  vicinities. As shown in Figure 3, the values for  $\lambda_{Center}$  are significantly higher around  $P_S$  than around  $NP_S$  ( $p \ll 0.0001$ ,  $r = 0.763$ ), especially for the two immediate neighbors of  $P_S$ , i.e. P.min1 and P.plus1. Post-hoc tests evaluated this finding and confirmed that the immediate

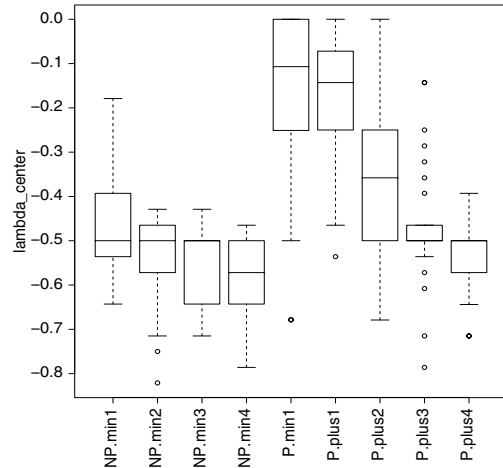


Figure 3:  $\lambda_{Center}$  for the *statement* category differs significantly between NP and P trials.

neighbors of  $P_S$  differ significantly in their values for  $\lambda_{Center}$  from all other stimuli in the surrounding of  $P_S$  or  $NP_S$ . Another correlation ( $p \ll 0.0001$ ,  $r = 0.425$ ) was found for the response criterion and the results of the goodness rating task for the  $P_S$  environment, with the response criterion increasing with better goodness rating values, i.e. the higher the goodness rating value the lower the hit rate for the environment of the prototype. So there is reduced discriminability in the surrounding of  $P_S$  but not in the surrounding of  $NP_S$ . This is exactly what PME assumes: perception is warped around P but not around NP. Thus, we found strong evidence for PME for the *statement* category in German.

#### 3.3.3. Question category

For the *question* category there are no significant differences between the hit rates of the immediate environments of  $P_Q$  and  $NP_Q$  (Figure 4). The same holds for the response criterion  $\lambda_{Center}$ : both surroundings do not differ significantly in their  $\lambda_{Center}$  values. But as in the category *statement*, there is a correlation between  $\lambda_{Center}$  and the trials ( $p \ll 0.0001$ ,  $r = 0.721$ ). There are significant differences in the mean values for hit rates and  $\lambda_{Center}$  ( $p = 0.005$ ) between the first and the second immediate neighbors of  $NP_Q$ , i.e. between NP.plus1 and NP.plus2; between the two immediate  $P_Q$  neighbors (P.min1 and P.plus1) and the second  $P_Q$  neighbor (P.min2); and between the second (P.min2) and the third (P.min3)  $P_Q$  neighbors. The result indicates that the discrimination ability around the supposed prototype of this category is worse than around the nonprototype, but this difference is found only with the second neighbor of  $P_Q$  and  $NP_Q$ , respectively, and it is far from reaching significance. We conclude that there is no evidence for a magnet effect in the *question* category in German.

## 4. Discussion

The results of our experiments show that a perceptual magnet exists for the *statement* category in German. There were only slight differences between subjects in the results of the identification, the goodness rating and the discrimination for this cat-

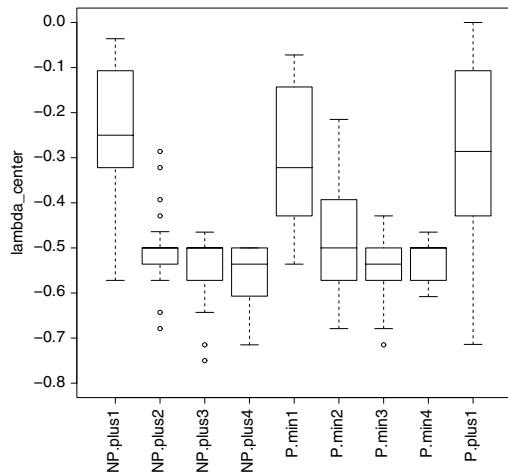


Figure 4:  $\lambda_{Center}$  for the category question shows minor differences between NP and P trials.

egory. We therefore conclude that the *statement* category with its low boundary tone is well established in German and has clear restrictions and contours. We successfully determined a prototype of this category which shows a very low  $F_0$ . As this prototype was almost the lowest one in the stimulus continuum we created and still was accepted as sounding naturally, we suppose that the most important cue for the perception of *statement* is its low boundary tone.

For the category *question* there are no such clear results. There was no evidence for a perceptual magnet in this category. This finding may be explained in different ways. First, there might be a third boundary tone called continuation (%). This boundary tone differs from L% in the height of  $F_0$  and from H% only in being non-terminal. A high but non-terminal boundary tone signals that the speaker will continue with his turn, whereas a high and terminal boundary tone (H%) signals that the listener may take the turn. Therefore it might be the case that the better discrimination ability in the *question* category is a consequence of discriminating within a perceptual space where two boundary tones are present, possibly comprising two perceptual magnets. This assumption might explain why the discrimination values for the immediate  $NP_Q$  neighbor are as bad as for the immediate neighbors of  $P_Q$ :  $P_Q$  corresponds to the *question* prototype and  $NP_Q$  corresponds to the continuation prototype (and not to the nonprototype of the *question* category as we supposed). However, we did not find clear evidence for the existence of a third boundary tone category in German in our identification task.

Second, according to the fixed step size in ERB during stimulus creation the differences in Hz between the *question* stimuli are larger than those between the *statement* stimuli. In our earlier experiment [2] we had mentioned that the better discrimination ability within the *question* category might be a test artefact because the step size of 0.35 ERB might be too large for this category. To check this possibility one would have to create a new stimulus set with a smaller step size than we used here.

The third explanation uses arguments from exemplar theory. If each category emerges from all the exemplars the listener perceived, then the definition of a prototype of a category states that this is the place in the exemplar cloud with the highest exemplar density. Discrimination is almost impossible there be-

cause the exemplars are so close to each other. Precisely at this point goodness ratings are expected to be maximal. The goodness ratings for the *question* category demonstrate that several subjects do not accept the highest stimuli as good exemplars of this category. Maybe these subjects have developed different exemplar clouds for the category *question*. If so, they may not accept the highest stimuli as questions and use other, possibly nonlinguistic, criteria during discrimination.

## 5. Conclusions

In this experiment we demonstrated that the concept of the perceptual magnet effect can be applied to the perception of intonation. There is clear evidence for the existence of one perceptual magnet in the *statement* category in German, as perception is warped around the prototype of this category, which results in a low discrimination rate around the prototype of the *statement* category. Perception is not warped around the nonprototypes in this category, i.e. discrimination of different stimuli of this category is quite good. This result could not be repeated for the German *question* category: discrimination in this category is quite good in the entire stimulus set and perception is not warped around one specific point in the exemplar cloud. Therefore, we conclude that in German no prototype exists for the *question* category, but a clear prototype does exist for the *statement* category.

## 6. Acknowledgements

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