Abstract
This paper presents the results of a series of experiments which examine the impact of two information status categories (given and new) and frequency of occurrence on pitch accent realisations. More specifically the experiments explore within-type similarity of pitch accent productions and the effect information status and frequency of occurrence have on these productions. The results indicate a significant influence of both pitch accent type and information status category on the degree of within-type variability, in line with exemplar-theoretic expectations.

1 Introduction
It seems both intuitive and likely that prosody should have a significant role to play in marking information status in speech. While there are well established expectations concerning typical associations between categories of information status and categories of pitch accent, e.g. rising L*H accents are often a marker for givenness, there is nevertheless some variability here (Baumann, 2006). Furthermore, little research has focused on how pitch accent tokens of the same type are realised nor have the effects of information status and frequency of occurrence been considered.

From the perspective of speech technology, the tasks of automatically inferring and assigning information status clearly have significant importance for speech synthesis and speech understanding systems.

The research presented in this paper examines a number of questions concerning the relationship between two information status categories (new and given), and how tokens of associated pitch accent types are realised. Furthermore the effect of frequency of occurrence is also examined from an exemplar-theoretic perspective.

The questions directly addressed in this paper are as follows:

1. How are different tokens of a pitch accent type realised?
   Does frequency of occurrence of the pitch accent type play a role?

2. What effect does information status have on realisations of a pitch accent type?
   Does frequency of occurrence of the information status category play a role?

3. Does frequency of occurrence in pitch accents and in information status play a role, i.e. is there a combined effect?

In examining the realisation of pitch accent tokens, their degree of similarity is the characteristic under investigation. Similarity is calculated by determining the cosine of the angle between pairs of pitch accent vector representations (see section 6).

The results in this study are examined from an exemplar-theoretic perspective (see section 3). The expectations within that framework are based upon two different aspects. Firstly, it is expected that, since all exemplars are stored, exemplars of a type that occur often, offer the speaker a wider selection of exemplars to choose from during production (Schweitzer and Möbius, 2004), i.e. the realisations are expected to be more variable than those of a rare type. However, another aspect of Exemplar Theory has to be considered, namely entrenchment (Pierrehumbert, 2001; Bybee, 2006). The central idea here is that frequently occurring behaviours undergo processes of entrenchment, they become in some sense routine. Therefore realisations of a very frequent type are expected to be realised similar to each other. Thus, similarity and variability are expressions of the same characteristic: the higher the degree of similarity of pitch accent tokens, the lower their realisation variability.
The structure of this paper is as follows: Section 2 briefly examines previous work on the interaction of information status categories and pitch accents. Section 3 provides a short introduction to Exemplar Theory. In this study similarity of pitch accent realisations on syllables, annotated with the information status categories of the words they belong to, is examined using the parametric intonation model (Möller, 1998) which is outlined in Section 4. Section 5 discusses the corpus employed. Section 6 introduces a general methodology which is used in the experiments in Sections 7, 8 and 9. Section 10 then presents some discussion, conclusions and opportunities for future research.

2 Information Status and Intonation

It is commonly assumed that pitch accents are the main correlate of information status\(^1\) in speech (Halliday, 1967). Generally, accenting is said to signal novelty while deaccenting signals given information (Brown, 1983), although there is counter evidence: various studies note given information being accentuated (Yule, 1980; Bard and Aylett, 1999). Terken and Hirschberg (1994) point out that new information can also be deaccented.

As for the question of which pitch accent type (in terms of ToBI categories (Silverman et al., 1992)) is typically assigned to different degrees of givenness. Pierrehumbert and Hirschberg (1990) find H\(+\) to be the standard novelty accent for English, a finding which has also been confirmed by Baumann (2006) and Schweitzer et al. (2008) for German. Given information on the other hand, if accented at all, is found to carry L\(\ast\) accent in English (Pierrehumbert and Hirschberg, 1990). Baumann (2006) finds deaccentuation to be the most preferred realisation for givenness in his experimental phonetics studies on German. However, Baumann (2006) points out that H+L\(\ast\) has also been found as a marker of givenness in a German corpus study. Previous findings on the corpus used in the present study found L\(\ast\)H being the typical marker for givenness (Schweitzer et al., 2008).

Leaving the phonological level and examining correlates of information status in acoustic detail, Kohler (1991) reports that in a falling accent, an early peak indicates established facts, while a medial peak is used to mark novelty. In a recent study Kügler and Féry (2008) found givenness to lower the high tones of prenuclear pitch accents and to cancel them out postnuclearly. These findings among others (Kügler and Féry, 2008) motivate an examination of the acoustic detail of pitch accent shape across different information status categories.

The experiments presented here go one step further, however, in that they also investigate potential exemplar-theoretic effects.

3 Exemplar Theory

Exemplar Theory is concerned with the idea that the acquisition of language is significantly facilitated by repeated exposure to concrete language input, and it has successfully accounted for a number of language phenomena, including diachronic language change and frequency of occurrence effects (Bybee, 2006), the emergence of grammatical knowledge (Abbot-Smith and Tomasello, 2006), syllable duration variability (Schweitzer and Möbius, 2004; Walsh et al., 2007), entrenchment and lenition (Pierrehumbert, 2001), among others. Central to Exemplar Theory are the notions of exemplar storage, frequency of occurrence, recency of occurrence, and similarity. There is an increasing body of evidence which indicates that significant storage of language input exemplars, rich in detail, takes place in memory (Johnson, 1997; Croot and Rastle, 2004; Whiteside and Varley, 1998). These stored exemplars are then employed in the categorisation of new input percepts. Similarly, production is facilitated by accessing these stored exemplars. Computational models of the exemplar memory also argue that it is in a constant state of flux with new inputs updating it and old unused exemplars gradually fading away (Pierrehumbert, 2001).

Up to now, virtually no exemplar-theoretic research has examined pitch accent prosody (but see Marsi et al. (2003) for memory-based prediction of pitch accents and prosodic boundaries, and Walsh et al. (2008)(discussed below)) and to the authors’ knowledge this paper represents the first attempt to examine the relationship between pitch accent prosody and information status from an exemplar-theoretic perspective. Given the considerable weight of evidence for the influence of frequency of occurrence effects in a variety of other linguistic domains it seems reasonable to explore such effects on pitch accent and information sta-

\(^1\)The term information status is used in (Prince, 1992) for the first time. Before that the terms givenness, novelty or information structure were used for these concepts.
tus realisations. For example, what effect might givenness have on a frequently/infrequently occurring pitch accent? Does novelty produce a similar result?

The search for possible frequency of occurrence effects takes place with respect to pitch accent shapes captured by the parametric intonation model discussed next.

4 The Parametric Representation of Intonation Events - PaIntE

The model approximates stretches of F₀ by employing a phonetically motivated model function (Möhlér, 1998). This function consists of the sum of two sigmoids (rising and falling) with a fixed time delay which is selected so that the peak does not fall below 96% of the function’s range. The resulting function has six parameters which describe the contour and were employed in the analysis: parameters a₁ and a₂ express the gradient of the accent’s rise and fall, parameter b describes the accent’s temporal alignment (which has been shown to be crucial in the description of an accent’s shape (van Santen and Möbius, 2000)), c₁ and c₂ model the ranges of the rising and falling amplitude of the accent’s contour, respectively, and parameter d expresses the peak height of the accent.² These six parameters are thus appropriate to describe different pitch accent shapes.

For the annotation of intonation the GToBI(S) annotation scheme (Mayer, 1995) was used. In earlier versions of PaIntE, the approximation of the F₀-contour for H+L and H* was carried out on the accented and post–accented syllables. However, for these accents the beginning of the rise is likely to start at the preaccented syllable. In the current version of PaIntE the window used for the approximation of the F₀-contour for H+L and H* accents has been extended to the preaccented syllable. In the case of discrepancies, took a final decision. Nevertheless, the annotation process was set up in a way to ensure a maximal smoothing of uncertainties. Texts were independently labelled by two annotators. Subsequently, a third, more experienced annotator compared the two results and, in the case of discrepancies, took a final decision. The rich annotation scheme employed in the corpus makes establishing inter-annotator agreement a time-consuming task which is currently underway. Nevertheless, the annotation process was set up in a way to ensure a maximal smoothing of uncertainties. Texts were independently labelled by two annotators. Subsequently, a third, more experienced annotator compared the two results and, in the case of discrepancies, took a final decision.

5 Corpus

The experiments that follow (sections 7, 9 and 8), were carried out on German pitch accents from the corpus. This corpus was automatically segmented and manually labelled according to GToBI(S) (Mayer, 1995). In the corpus, 1233 syllables are associated with an L+H accent, 704 with an H+L accent and 162 with an H* accent.

The corpus contains data from three speakers, two female and a male one, but the majority of the data is produced by the male speaker (888 L+H accents, 527 H+L accents and 152 H* accents). In order to maximise the number of tokens, all three speakers were combined. Of the analysed data, 77.92% come from the male speaker. However, it is not necessarily the case that the same percentage of the variability also comes from this speaker: Both, PaIntE and z-scoring (cf. section 6) normalise across speakers, so the contribution from each individual speaker is unclear.

The textual transcription of the corpus was annotated with respect to information status using the annotation scheme proposed by Riester (2008). In this taxonomy information status categories reflect the default contexts in which presuppositions are resolved, which include e.g. discourse context, environment context or encyclopaedic context.

The annotations are based solely on the written text and follow strict semantic criteria. Given that textual information alone (i.e. without prosodic or speech related information) is not necessarily sufficient to unambiguously determine the information status associated with a particular word, there are therefore cases where words have multiple annotations, reflecting underspecification of information status. However, it is important to note that in all the experiments reported here, only unambiguous cases are considered.

In the present study the categories given and new are examined. These categories do not represent a binary distinction but are two extremes from a set of clearly distinguished categories. For the most part they correspond to the categories textually given and brand-new that are used in Bau-
mann (2006), but their scope is more tightly con-
strained. The information status annotations are
mapped to the phonetically transcribed speech sig-
nals, from which individual syllable tokens bear-
ing information status are derived.

Syllables for which one of the PaIntE-
parameters was identified as an outlier, were re-
moved. Outliers were defined such that the upper
2.5 percentile as well as the lower 2.5 percentile
of the data were excluded. This led to
a reduced number of pitch accent tokens: 1021 L\^{\star}H accents,
571 H\^{\star}L accents and 134 H\^{\star} accents. Thus, there
is a continuum of frequency of occurrence, high to
low, from L\^{\star}H to H\^{\star}.

With respect to information status, 102 L\^{\star}H ac-
cents, 87 H\^{\star}L accents and 21 H\^{\star} accents were un-
ambiguously labelled as
new. For givenness the
number of tokens is: 114 L\^{\star}H accents, 44 H\^{\star}L ac-
cents and 10 H\^{\star} accents.

6 General Methodology

In the experiments the general methodology for
calculation of similarity detailed in this section
was employed.

For tokens of the pitch accent types L\^{\star}H, H\^{\star}L
and H\^{\star}, each token was modelled using the full
set of PaIntE parameters. Thus, each token was
represented in terms of a 6-dimensional vector.

For each of the pitch accent types the following
steps were carried out:

- For each 6-dimensional pitch accent category
token calculate the z-score value for each di-
mension. The z-score value represents the
number of standard deviations the value is
away from the mean value for that dimension and
allows comparison of values from different
normal distributions. The z-score is given by:

\[ z = \frac{\text{value}_{\text{dim}} - \text{mean}_{\text{dim}}}{\text{sdev}_{\text{dim}}} \]  

Hence, at this point each pitch accent is repre-
sented by a 6-dimensional vector where each
dimension value is a z-score.

- For each token z-scored vector calculate how
similar it is to every other z-scored vector
within the same pitch accent category, and,
in Experiment 2 and 3, with the same infor-
mation status value (e.g. new), using the co-
sine of the angle between the vectors. This is given by:

\[ \cos(\vec{i}, \vec{j}) = \frac{\vec{i} \cdot \vec{j}}{\| \vec{i} \| \| \vec{j} \|} \]  

where \( i \) and \( j \) are vectors of the same pitch ac-
cent category and \( \cdot \) represents the dot prod-
uct.

Each comparison between vectors yields a
similarity score in the range [-1,1], where -1
represents high dissimilarity and 1 represents
high similarity.

The experiments that follow examine distribu-
tions of token similarity. In order to establish
whether distributions differ significantly two dif-
ferent levels of significance were employed, de-
pending on the number of pairwise comparisons
performed.

When comparing two distributions (i.e. per-
forming one test), the significance level was set to
\( \alpha = 0.05 \). In those cases where multiple tests were
 carried out (Experiment 1 and Experiment 3), the
level of significance was adjusted (Bonferroni cor-
rection) according to the following formula:

\[ \alpha = 1 - \left(1 - \alpha_1\right)^{\frac{1}{n}} \]  

where \( \alpha_1 \) represents the target significance level
(set to 0.05) and \( n \) represents the number of tests
being performed. The Bonferroni correction is of-
ten discussed controversially. The main criticism
concerns the increased likelihood of type II errors
that lead to non-significance of actually significant
findings (Pernegger, 1998). Although this conser-
vative adjustment was applied, the statistical tests
in this study resulted in significant p-values indi-
cating the robustness of the findings.

7 Experiment 1: Examining frequency of
occurrence effects in pitch accents

In accordance with the general methodology set
out in section 6, the PaIntE vectors of pitch ac-
cent tokens of types L\^{\star}H, H\^{\star}L, and H\^{\star} were all
z-scored and, within each type, every token was
compared for similarity against every other token
of the same type, using the cosine of the angle be-
tween their vectors. In essence, this experiment
illustrates how similarly pitch accents of the same
type are realised.

Figure 1 depicts the results of the analysis. It
shows the density plot for each distribution of
cosine-similarity comparison values, whereby the
Figure 1: Density plots for similarity within pitch accent types. All distributions differ significantly from each other. There is a trend towards greater similarity from high-frequency L*H to low-frequency H*.

Walsh et al. (2008) also reported significant differences between these distributions, however, there did not appear to be a clear frequency of occurrence effect. The results in the present study differ from their results because the distributions centre around different ranges of the similarity scale clearly indicating that each accent type behaves differently in terms of similarity/variability between the tokens of the respective type. The differences between the two findings can be ascribed to the augmented PaIntE model (section 4).

Given the results from this experiment, the next experiment seeks to establish what relationship, if any, exists between information status and pitch accent production variability.

8 Experiment 2: Examining frequency of occurrence effects in information status categories

This experiment was carried out in the same manner as Experiment 1 above with the exception that in this experiment a subset of the corpus was employed: only syllables that were unambiguously labelled with either the information status category new or the category given were included in the analyses. The experiment aims to investigate the effect of information status on the similarity/variability of tokens of different pitch accent types. For each pitch accent type, tokens that were labelled with the information status category new...
were compared to tokens labelled as given. Again, a pairwise Kolmogorov-Smirnov test was applied for each comparison ($\alpha = 0.05$). Figure 2 depicts the results for H+L accents. The K-S test yielded a highly significant difference between the two distributions ($p \ll 0.001$), reflecting the clearly visible difference between the two curves. It is noteworthy here that for H+L the information status category new is more frequent than the category given. Indeed, approximately twice as many are labelled as new than those labelled given. Figure 2 illustrates that new H+L accents are realised more variably than given ones. That is, again, an increase in frequency of occurrence co-occurs with an increase in similarity, this time at the level of information status.

Figure 3 depicts the difference in similarity/variability for L+H between new tokens and given tokens. It is clearly visible that the two curves do not differ as much as those under the H+L condition. Both curves centre around zero reflecting the fact that for both types the tokens are variable. Although the Kolmogorov-Smirnov test indicates significance ($\alpha = 0.05$, $p = 0.044$), the nature of the impact that information status has in this case is unclear.

Here again an effect of frequency of occurrence might be the reason for this result. The high frequency of L+H accents in general results in a relative high frequency of given L+H tokens. So the token number for both types is similar (102 new L+H tokens vs. 114 given L+H tokens), there is high frequency in both cases, hence variability.

These results, particularly in the case of H+L (fig. 2) indicate that information status affects pitch accent realisation. The next experiment compares the effect across different pitch accent types.

9 Experiment 3: Examining the effect of information status across pitch accent types

This experiment was carried out in the same manner as Experiments 1 and 2 above. For each pitch accent type, figure 4 depicts within-type pitch accent similarity for tokens unambiguously labelled as new.

As with Experiments 1 and 2, frequency of occurrence once more appears to play a significant role. Again, all Kolmogorov-Smirnov tests yielded significant results ($p < 0.017$ in all cases). Indeed, the difference between the distributions of L+H, H+L, and H+ similarity plots appears to be considerably more prominent than in Experiment 1 (see fig. 1). This indicates that under the condition of novelty the frequency of occurrence effect is more pronounced. In other words, there is a considerably more noticeable difference across the distributions of L+H, H+L and H+, when nov-
Density plots for similarity of given tokens across pitch accent types. Mid-frequency H+L displays greater similarity than high-frequency L+H. For lowest frequency H* (only 10 tokens) the trend cannot be observed.

Figure 5: Density plots for similarity of given tokens across three pitch accent types. Mid-frequency H+L displays greater similarity than high-frequency L+H. For lowest frequency H* (only 10 tokens) the trend cannot be observed.

... that frequencey of occurrence effect. However, having only ten tokens (as described in Experiment 1): the information status category given compounds the frequency of occurrence effect for given tokens than for all accents pooled (as described in Experiment 1): the information status category given compounds the frequency of occurrence effect for L+H and H+L.

For H* the result is not as clear as for the two more frequent accents. The comparison between H* and L+H results in a significant difference ($p < 0.017$) whereas the comparison between H* and H+L is slightly above the conservative significance level ($p = 0.0186$). Moreover, the distribution is centred between the distributions for L+H and H+L and it is thus not clear how to interpret this result with respect to a possible frequency of occurrence effect. However, having only ten instances of given H*, the explanatory power of these comparisons is questionable.

10 Discussion

The experiments discussed above yield a number of interesting results with implications for research in prosody, information status, the interaction between the two domains, and for exemplar theory.

Returning to the first question posed at the outset in section 1, it is quite clear from Experiment 1 that a certain amount of variability exists when different tokens of the same pitch accent type are produced. It is also clear, from the same experiment, that the frequency of occurrence of the pitch accent type does indeed play a role: with an increase in frequency comes an increase in variability. This result is in line with the exemplar-theoretic view that since all exemplars are stored, exemplars of a type that occur often are more variable because they offer the speaker a wider selection of exemplars to choose from during production (Schweitzer and Möbius, 2004). However, with respect to entrenchment (Pierrehumbert, 2001; Bybee, 2006), i.e. the idea that frequently occurring behaviours undergo processes of entrenchment, in Experiment 1 one might expect to see greater similarity in the realisations of L+H. However, it is important to note that while tokens of L+H are not particularly similar to each other (the bulk of the distribution is around zero (see figure 1)), they are not too dissimilar either. That is, they rest at the midpoint of the similarity continuum produced by cosine calculation, in quite a normal looking distribution. This is not at odds with the idea of entrenchment. As productions of a pitch accent type become more frequent, the distribution of similarity spreads from the right side of the graph (where infrequent and highly similar H* tokens lie) leftwards (through H+L) to the point where the L+H distribution is found. Beyond this point tokens are excessively different.

The second question posed in section 1, and addressed in Experiment 2, sought to ascertain the impact, if any, information status has on pitch accent realisation. Distributions of given and new H+L similarity scores differed significantly, as did distributions of given and new L+H similarity scores, indicating that information status affects realisation. In other words, for both pitch accent types, given and new tokens behave differently. Concerning the frequency of occurrence of the information status categories, certainly in the case of H+L the higher frequency new tokens exhibited more variability. In the case of L+H similar numbers of new and given tokens, possibly due to the high frequency of L+H in general,
led to visually similar yet significantly different distributions. Once again sensitivity to frequency of occurrence seems to be present, in line with exemplar-theoretic predictions.

The final question concerns the possibility of a combined effect of pitch accent frequency of occurrence and information status frequency of occurrence. Figures 4 and 5 depict a clear compounding effect of both information status categories across the different pitch accent types (and their inherent frequencies) when compared to figure 1. Interestingly, the less frequently occurring given appears to have a greater impact, particularly on high frequency L+H.

Figure 6 displays all possible combinations of L+H, H+L, given and new. H+ is omitted in this graph because of the small number of tokens (10 given, 21 new) and the resulting lack of explanatory power. It is evident that an overall frequency of occurrence effect can be observed: “given L+H” and “new L+H” to mid-frequency “new H+L” and low-frequency “given H+L.”

These results highlight an intricate relationship between pitch accent production and information status. The information status of the word influences not only the type and shape of the pitch accent (Pierrehumbert and Hirschberg, 1990; Baumann, 2006; Kügler and Féry, 2008; Schweitzer et al., 2008) but also the similarity of tokens within a pitch accent type. Moreover, this effect is well explainable within the framework of Exemplar Theory as it is subject to frequency of occurrence: tokens of rare types are produced more similar to each other than tokens of frequent types.

In the context of speech technology, unfortunately the high variability in highly frequent pitch accents has a negative consequence, as the correlation between a certain pitch accent or a certain information status category and the F0 contour is not a one-to-one relationship. However, forewarned is forearmed and perhaps a finer grained contextual analysis might yield more context specific solutions.

11 Future Work

The methodology outlined in section 6 gives a lucid insight into the levels of similarity found in pitch accent realisations. Further insights, however, could be gleaned from a fine-grained examination of the PaIntE parameters. For example, which parameters differ and under what conditions when examining highly variable tokens? Information status evidently plays a role in pitch accent production but the contexts in which this takes place have yet to be examined. In addition, the role of information structure (focus-background, contrast) also needs to be investigated. A further line of research worth pursuing concerns the impact of information status on the temporal structure of spoken utterances and possible compounding with frequency of occurrence effects.

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