Restructuring the Melodic Content of Feet

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1. Introduction[1]

The topic of this paper is how rhythmic variability in speech can be accounted for both phonologically and phonetically. The question is whether a higher speech rate leads to adjustment of the phonological structure, or just to 'phonetic compression', i.e. shortening and merging of vowels and consonants, with preservation of the phonological structure. We claim that the melodic content of a phonological domain is indeed adjusted when the speech rate increases. In other words, every speech rate has its own register, in terms of Optimality Theory (Prince and Smolensky 1993) its own ranking of constraints.

We will investigate prosodic variability as part of our main research project, which involves a comparison of the analyses of music and language. Our ultimate aim is to provide evidence for the assumption that every temporal behavior is structured similarly (cf. Liberman 1975). Gilbers and Schreuder (to appear) show that Optimality Theory owes a lot to the constraint-based music theory of Lerdahl and Jackendoff (1983). Based on the great similarities between language and music we claim that musical knowledge can help in solving linguistic issues.

In this paper, we will show that clashes are avoided in allegro tempo. In both language and music distances between beats are enlarged, i.e. there appears to be more melodic content between beats. To illustrate this, we ran a pilot experiment in which we elicited fast speech. As expected, the data show rhythmically variable patterns dependent on speech rate. The paper is organized as follows. In section 2 the data of the experiment are introduced. Section 3 is addressed to the phonological framework of Optimality Theory and the different rankings of andante and allegro speech. The method of the experiment is discussed in section 4 and the phonetic analysis plus the results follow in section 5. The perspectives of our analysis will be discussed in the final section.

2. Data

We will discuss three types of rhythmic variability in Dutch. The first we will call “stress shifts to the right”; the second “stress shifts to the left” and the third “beat reduction”. In the first type as exemplified in *stúdietòelage (s w s w w)* ‘study grant’, we assume that this compound can be realized as *stúdietoelàge (s w w s w)* in allegro speech. *Perfèctionίst (w s w s)* is an example of “stress shift to the left” and we expect a realisation*pèrfectionίst (s w w s)* in allegro speech. The last type does not concern a stress shift, but a stress reduction. In *zuidafrikaans (s s w s)* ‘South African’ compounding of *zuid* and *afrikaans* results in a stress clash. In fast speech this clash is avoided by means of reducing the second beat: *zuidafrikaans (s w w s)*. Table 1 shows a selection of our data.

Table 1. Data

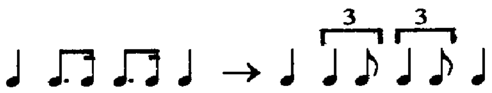
Type 1: stress shift to the right (andante: s w s w w; allegro: s w w s w)	
stu die toe la ge	‘study grant’
weg werp aan ste ker	‘disposable lighter’
ka mer voor zit ter	‘chairman of the House of Parliament’
Type 2: stress shift to the left (andante: w s w s; allegro: s w w s)	
per fec tio nist	‘perfectionist’
a me ri kaan	‘American’
vi ri li teit	‘virility’
Type 3: beat reduction (andante: s s w s; allegro: s w w s)	
zuid a fri kaans	‘South African’
schier mon nik oog	‘name of an island’
gre go ri aans	‘Gregorian’

The different rhythmic patterns are accounted for phonologically within the framework of OT.

3. Framework and phonological analysis

The mechanism of constraint interaction, the essential characteristic of OT, is also used in the generative theory of tonal music (Lerdahl and Jackendoff, 1983). In both frameworks, constraint satisfaction determines grammaticality and in both frameworks the constraints are potentially conflicting and soft, which means violable. Violation, however, is only allowed if it leads to satisfaction of a more important, higher ranked constraint. The great similarities between these theoretical frameworks make comparison and interdisciplinary research possible.

For example, restructuring rhythm patterns as a consequence of a higher playing rate is a very common phenomenon in music. In Figure 1 we give an example of re-/misinterpretation of rhythm in accelerated or sloppy playing.



dotted notes rhythm → triplet rhythm

Figure 1. Rhythmic restructuring in music

In Figure 1, the "dotted notes rhythm" (left of the arrow) is played as a triplet rhythm (right of the arrow). In the dotted notes rhythm the second note has a duration which is three times as long as the third, and in the triplet rhythm the second note is twice as long as the third. In fast playing it is easier to have equal durations between note onsets. Clashes are thus avoided and one tries to distribute the notes, the melodic content, over the measures as evenly as possible, even if this implies a restructuring of the rhythmic pattern. To ensure that the beats do not come too close to each other in fast playing, the distances are enlarged, thus avoiding a staccato-like rhythm. In short, in fast tempos the musical equivalents of the Obligatory Contour Principle (OCP), a prohibition on adjacency of identical elements in language (McCarthy 1986), become more important.

We claim that - just as in music - the allegro patterns in all the different types of data in Table 1 are caused by clash avoidance. There is a preference for beats that are more evenly distributed over the phrase. The different structures can be described phonologically as a conflict between markedness constraints, such as FOOT REPULSION (*ΣΣ) (Kager 1994), and OUTPUT - OUTPUT CORRESPONDENCE constraints (cf. Burzio 1998) within the framework of OT. FOOT REPULSION prohibits adjacent feet and consequently prefers a structure in which feet are separated from each other by an unparsed syllable. This constraint is in conflict with PARSE-σ, which demands that every syllable is part of a foot. OUTPUT - OUTPUT CORRESPONDENCE compares the structure of a phonological word with the structure of its individual parts. For example, in a word such as *fototoestel* 'photo camera', OUTPUT - OUTPUT CORRESPONDENCE demands that the rhythmic structure of its part *tóestel* 'camera' with a stressed first syllable is reflected in the rhythmic structure of the output. In other words, OUTPUT - OUTPUT CORRESPONDENCE prefers *fótotòestel*, with secondary stress on *toe*, to *fótotoestèl*, with secondary stress on *stel*.

Whereas the normal patterns in andante speech satisfy OUTPUT - OUTPUT CORRESPONDENCE, the preference for triplet patterns in fast speech is accounted for by means of dominance of the markedness constraint, FOOT REPULSION, as illustrated in Table 2.[2]

Table 2. Rhythmic restructuring in language

a. ranking in andante speech:

constraints → *fototoestel* candidates ↓		OUTPUT - OUTPUT CORRESPONDENCE	*ΣΣ	PARSE-σ
☞	(fóto)(tòestel)		*	
	(fóto)toe(stèl)	*!		*

b. ranking in allegro speech:

constraints → *fototoestel* candidates ↓		*ΣΣ	OUTPUT - OUTPUT CORRESPONDENCE	PARSE-σ
	(fóto)(tòestel)	*!		
☞	(fóto)toe(stèl)		*	*

Dutch is described as a trochaic language (Neijt and Zonneveld 1982). Table 2a shows a preference for an alternating rhythm. The dactyl pattern as preferred in Table 2b, however, is the default rhythmic pattern of prosodic words in languages such as Estonian and Cayuvava: every strong syllable alternates with two weak syllables (cf. Kager 1994). We assume that the rhythm grammar, i.e. constraint ranking, of Dutch allegro speech resembles the grammar of these languages. In the next section we will explore whether we can find empirical evidence for our hypothesis.

4. Method

To find out whether people indeed prefer triplet patterns in allegro speech, we ran a pilot experiment in which we tried to elicit fast speech. Six subjects participated in a multiple-choice quiz in which they competed each other in answering twenty simple questions as quickly as possible. In this way, we expected them to speak fast without concentrating too much on their own speech. In Table 3 one of the quiz items is depicted.

Table 3. Quiz item

Q4	*President Bush is een typische*	'President Bush is a typical '
A1	*intellectueel*	'intellectual'
A2	*amerikaan*	'American'
A3	*taalkundige*	'linguist'

We categorized the obtained data as allegro speech. As a second task the subjects were asked to read out the answers at a normal speaking rate embedded in the sentence *ik spreek nu het woord … uit* 'now I pronounce the word … '. This normal speaking rate means that the subjects will produce the words at a rate of approximately 180 words per minute, which we categorize as andante speech. All data were recorded on minidisk in a soundproof studio and normalized to 100% in CoolEdit. After an auditive analysis, the data were phonetically analyzed in PRAAT (Boersma and Weenink 1992). We compared the andante and allegro data by measuring duration, pitch, intensity and spectral balance (Sluijter 1995). Sluijter claims that, respectively, duration and spectral balance are the main correlates of primary stress. In our experiment, we are concerned with secondary stress.

For the duration measurements, the rhymes of the relevant syllables were observed. For example, in the allegro style answer A2 *amerikaan* in Table 3, we measured the first two rhymes and compared the values in Msec. with the values for the same rhymes at the andante rate. In order to make this comparison valid, we equalized the total durations of both realizations by multiplying the duration of the allegro with a so-called 'acceleration factor', i.e. the duration of the andante version divided by the duration of the allegro version. According to Eefting and Rietveld (1989) and Rietveld and Van Heuven (1997), the just noticeable difference for duration is 4,5%. If the difference in duration between the andante and the allegro realization does not exceed this threshold, we consider the realizations as examples of the same speech rate and neglect them for further analysis.

For the pitch measurements, we took the value in Hz in the middle of the vowel. The just noticeable difference for pitch is 2,5% ('t Hart et al 1990). For the intensity measurements, we registered the mean value in dB of the whole syllable.

The last parameter we considered concerns the spectral balance. Sluijter (1995) claims that the spectral balance of the vowel of a stressed syllable is characterized by more energy in the higher frequency region, because of the changes in the source spectrum due to a more pulse-like shape of the glottal waveform. The vocal effort, which is used for stress, generates a strongly asymmetrical glottal pulse. As a result of the shortened closing phase, there is an increase of intensity around the four formants in the frequency region above 500 Hz. Following Sluijter (1995) we compared the differences in intensity of the higher and lower frequencies of the relevant syllables in both tempos.

5. Results

5.1. Auditive analysis

Before we can present an auditive analysis of the data, we have to find out whether or not the quiz design was successful. The results show that the quiz indeed triggers faster speech by the subjects. Figure 2 shows the total duration of Type 1 data (Right Shifts) of items realized in both andante and allegro speech by subject 1, who was representative for all subjects. The mean acceleration factor for Type 1 is 1.383; for Type 2 1.317 and for Type 3 1.333, which means that the mean acceleration factor for all types is 1.344.

The data also show that most subjects prefer the restructured patterns in allegro speech, as described in an OT-ranking with dominant markedness constraints, whereas the pattern reflecting a dominance of the correspondence constraints is observed more often in the andante tempo.

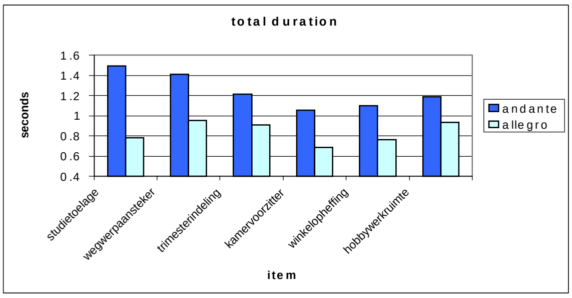


Figure 2. Total duration of Right Shifts (Type 1). Dark columns: duration item andante tempo; Light columns: duration item allegro tempo

Figure 3 shows our auditive analysis of all data of the six subjects. The first graph shows the andante realizations and the second graph the allegro realizations. For each subject represented on the horizontal axis, the light column indicates the number of expected realizations according to our hypothesis, whereas the dark column indicates the number of unexpected realizations on a total of 20. For example, in the andante tempo subject P1 realizes 13 items satisfying the correspondence constraints and 7 items satisfying the markedness constraints. In the allegro tempo, this same subject P1 realizes 4 items satisfying the correspondence constraints and 16 items satisfying the markedness constraints.

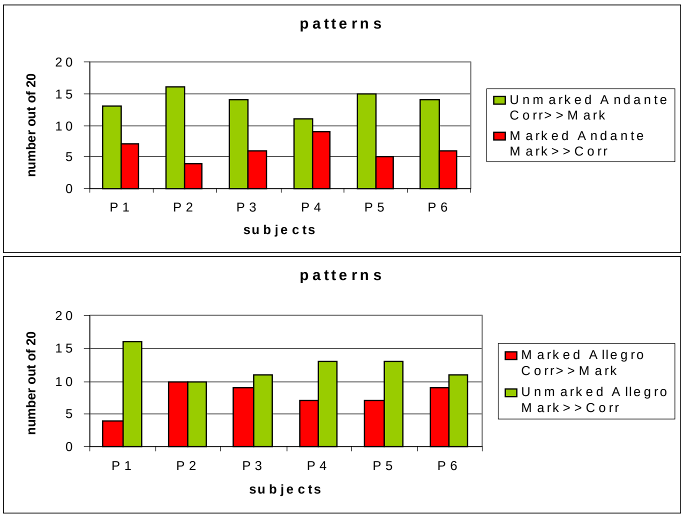


Figure 3. Auditive analysis of all data combined.

Obviously, there is a preference for restructuring the rhythmic pattern in allegro speech. However, it is not an absolute preference. Sometimes restructuring does not take place in allegro speech, but on the other hand restructured patterns also show up in andante speech.[3] Some items were realized with the same rhythmic pattern irrespective of the tempo. Therefore, we also looked at the word pairs with a different rhythmic pattern in both tempos for each subject. Clearly, the differences go in one direction, which is the expected pattern according to our hypothesis. Almost all of the word pairs with different rhythmic structures satisfy correspondence in andante tempo and markedness in allegro tempo. There are only a few counterexamples as depicted in the dark columns in Figure 4, where the subject prefers the restructured patterns in andante tempo.

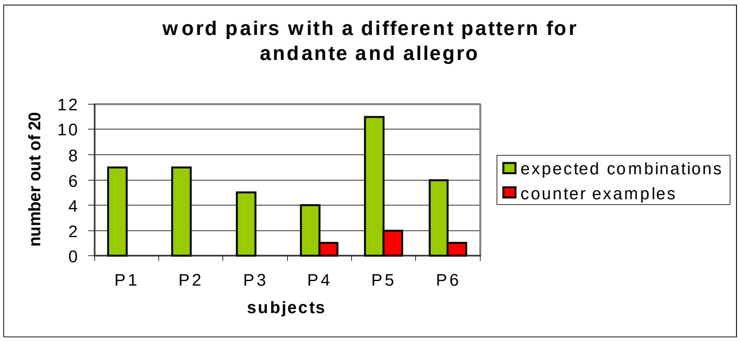


Figure 4. Word pairs with a different structure

Figure 4 sums up the results of all subjects with all three types of data combined. It turns out that the different types behave similarly. Although some items, such as *hobbywerkruimte* (Type 1) 'hobby room', never show a stress shift and other items, such as *viriliteit* (Type 2) 'virility', prefer the shifted pattern in both tempos for all subjects. We have no direct explanation for this observation, since word frequency and morphological structure do not seem to be triggers for restructuring in our data. Possibly, the syllable structure plays an important role; open syllables seem to lose stress more easily than closed ones. Nevertheless, Figure 4 confirms our hypothesis.

5.2. Acoustic analysis

In the current state of phonological research, embodied in e.g. laboratory phonology, much value is set on acoustic evidence for phonological analyses. Studies such as Sluijter (1995) and Sluijter and Van Heuven (1996) provide acoustic correlates for primary stress. In our study we are concerned with beat reduction and secondary stress shifts and we wonder whether or not the same acoustic correlates hold for secondary stress. Shattuck Hufnagel et al (1994) and Cooper and Eady (1986) do not find acoustic correlates of rhythmic stress at all. They claim that it is not entirely clear which acoustic correlates are appropriate to measure, since these correlates are dependent on the relative strength of the syllables of an utterance. The absolute values of a single syllable can hardly be compared without reference to their context and the intonation pattern of the complete phrase. Huss (1978) claims that some cases of perceived rhythmic stress shift may be perceptual rather than acoustic in nature. Grabe and Warren (1995) also suggest that stress shifts can only be perceived in rhythmic contexts. In isolation, the prominence patterns are unlikely to be judged reliably. In the remainder of this paper we try to find out if we can support one of these lines of reasoning. In other words, are we able to support our perceived rhythmic variability with a phonetic analysis? Therefore, we measured the duration, pitch, intensity and spectral balance of the relevant syllables as realized by subject P1.

Because Dutch is a quantity-sensitive language, the duration of the relevant syllable rhymes was considered. Onsets do not contribute to the weight of a syllable. In Figure 5, the duration analysis is shown for Type 2 data (left shifts). The four columns indicate, respectively, the duration of the rhyme of the first and second syllable in andante speech, and the duration of the first and second one in allegro speech. According to Sluijter (1995), duration is the main correlate of primary stress. As a starting point, we adopt her claim for our analysis of secondary stress. Our measurements would confirm our hypothesis and our auditive analysis, if the second column were higher than the first one and if the fourth column were lower than the third one. In that case, the subject would realize a word such as *perfectionist* as *perfèctioníst* in andante tempo and as *pèrfectioníst* in allegro tempo.

In the andante tempo, three out of six items show the dominant correspondence pattern and in the allegro tempo, four out of six items show the dominant markedness pattern. That is hardly a preference and it does not confirm our auditive analysis of the data of subject P1 as depicted in Figure 3. Furthermore, if we consider the word pairs with different patterns, there is only one pair that has the ideal ratio: the patterns of *amerikaan*.

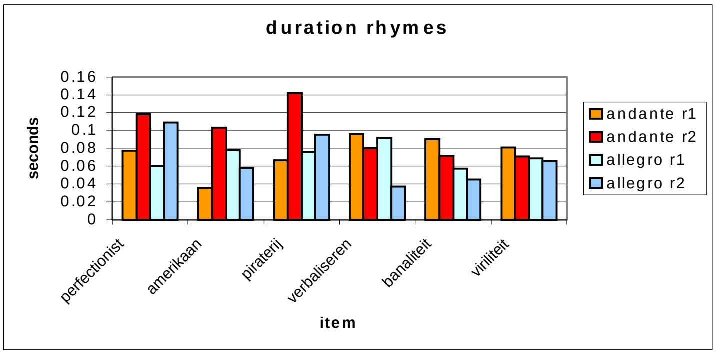


Figure 5. Duration (Type 2: Left Shifts)

If duration does not enable us to confirm our auditive findings, maybe pitch is the main stress correlate for this speaker. However, pitch measurements reveal the same fuzzy result as the duration measurements. Again, only one pattern confirms the auditive analysis. This time it is not the item *amerikaan*, but the item *perfectionist*. Moreover, the differences in pitch in this item do not exceed the threshold of the 2.5%, which is the just noticeable difference for pitch. We also analyzed the mean intensity value of the relevant vowels without recognizable patterns between allegro and andante style. These results support the analyses of Sluijter (1995) and Sluijter and Van Heuven (1996), who also claim that the intensity parameter does not contribute much to the perception of stress.

Finally, we considered the spectral balance. In order to rule out the influence of the other parameters, we monotonized the data for volume and pitch. Then we selected the relevant vowels and analyzed them as a cochleagram in PRAAT. In Figure 6 we show two cochleagrams of the vowel [a] in the fourth syllable of, respectively, *stúdietòelage* 'study grant' (Type 1) in andante tempo and *stúdietoelàge* in allegro tempo. This item was taken from a pre-study. The allegro data show the expected increased energy in the higher frequencies, indicated by means of shades of gray; the darker gray the more energy.

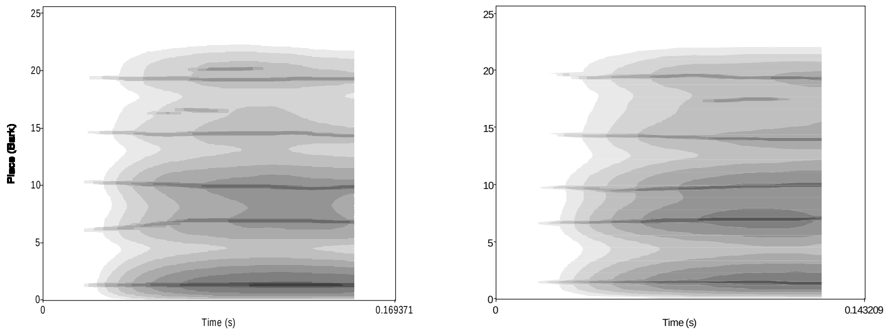


Figure 6. Cochleagrams of [a] in studietoelage *(vert.: Bark; horiz.: Sec)*

In Figure 6 we see that the andante version of [a] has more energy in the lower regions of approximately 2 Bark. This confirms the results of the study of primary stress in Sluijter (1995). The right cochleagram shows increased energy in the regions of approximately 5 to 22 Bark. If we convert this perceptive, almost logarithmic, Bark scale into its linear counterpart, the Hertz scale, this area correlates with the frequency region of 3 to 10 kHz.

In order to measure perceived secondary stress, we will measure the relative energy in the different frequency regions in Phon.[4] According to Sluijter (1995) stressed vowels have increased energy above 500 Hz compared to the same vowel in an unstressed position. This can be shown if we take a point in time from both cochleagrams in Figure 6 in which the energy of F1 reaches its highest value. In Figure 7 the values in Phon are depicted for these points and plotted against the Bark values in 25 steps.

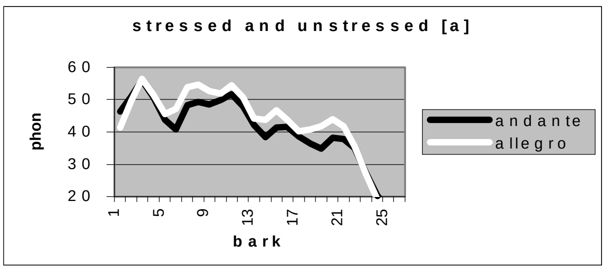


Figure 7. Energy in Phon

The white line in Figure 7 indicates the pattern of the allegro stressed [a] in *studietoelage* and the black line indicates the pattern of the andante unstressed [a]. We see increased energy in the region of 13 to 21 Bark, which correlates with the most sensitive region of our ear. The mean Phon value in Figure 7 between 5 and 21 Bark is 43.6 Phon for the andante unstressed [a] and 47.4 Phon for the allegro stressed [a]; a mean difference of 3.8 Phon.

Now, let us see whether or not we can find similar results for our subject P1. Figure 8 shows that the spectral balance confirms the leftward stress shift we perceived in the allegro realization of *amerikaan*. The first syllable vowel in allegro tempo is characterized by more energy in the higher frequency regions than its andante counterpart. In the second syllable vowel it is just the other way around.

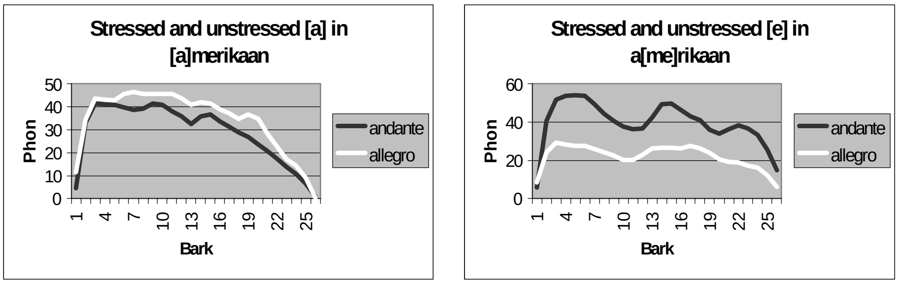


Figure 8. Spectral balance comparison of the first two vowels of amerikaan

Unfortunately, not all spectral balance data confirm our auditive analysis. For example, in 5.2, we claimed that the pitch analysis of the stress shift in *perfectionist* did confirm our auditive analysis. Therefore, we expected more energy in the allegro realization of the first vowel and less energy in the allegro realization of the second vowel, but it appeared that there is relatively more energy in the andante realization of *per*. This result contradicts our auditive and our pitch analysis.

We have to conclude that the different phonetic analyses contradict each other. Sometimes the perceived stress shift is characterized by a longer duration of the stressed syllable; sometimes a relatively higher pitch characterizes it. The results of our spectral balance analysis show that the differences in energy pattern with differences in duration. In our perceived stress shift in allegro *perfectionist*, pitch turned out to be the decisive correlate, whereas duration and spectral balance measurements indicated no shift at all. On the other hand, the perceived shift in allegro *amerikaan* was confirmed by the duration and spectral balance analyses together, whereas pitch measurements indicated the opposite pattern. For most perceived stress shifts, however, the acoustic correlates did not give any clue.

6. Discussion and Conclusion

In section 4, we presented our phonological account of the restructuring within the framework of OT. Our main conclusion is that phonetic compression cannot be the sole explanation of the different rhythm patterns. There are different grammars, i.e. constraint rankings, for different rates of speaking. In andante tempo, correspondence constraints prevail, whereas in allegro tempo markedness constraints dominate the correspondence ones, at least in a majority of the realizations. These preferences resemble the preferences of andante and allegro music. In both disciplines clashes are avoided in allegro tempo by means of enlarging the distances between beats.

In section 5, we attempted to confirm our phonological account with a phonetic analysis. Unfortunately, the phonetic correlates of stress - duration, pitch and intensity - do not show the expected and perceived differences in rhythm patterns in all pairs. Sluijter (1995) found out that duration is the main correlate of primary stress with spectral balance as an important second characteristic. In our analysis, however, neither differences in duration nor differences in spectral balance could identify secondary stress. Therefore, we have to conclude that our analysis supports earlier work by Shattuck Hufnagel et al (1994), Cooper and Eady (1986), Huss (1978) and Grabe and Warren (1995), who all claim that acoustic evidence for secondary stress cannot be found unambiguously. Although we did find some differences in duration, spectral balance or pitch, these differences were not systematically found in all pairs in which we perceived rhythmic variability. For future research we may consider hummed versions of the data in order to rule out the interference of intrinsic frequency values of the segments. Another advantage of such an analysis could be that it takes the rhythm from the timing of the syllable onsets instead of rhyme duration. At this point, the question remains: are we fooled by our brains and is there no phonetic correlate of the perceived phonological stress shifts in the acoustic signal or do we have to conclude that the real phonetic correlate of secondary stress has yet to be found?

Notes

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1. We wish to thank Grzegorz Dogil, Wilbert Heeringa, Fred Lerdahl, Hugo Quené, and Hidetoshi Shiraishi for their useful comments.
2. For reasons of clarity, we abstract from constraints such as FOOTBINARITY (FTBIN) and WEIGHT-TO-STRESS PRINCIPLE in Table 2. Although these constraints play an important role in the Dutch stress system (cf. Gilbers & Jansen, 1996), the conflict between OUTPUT-OUTPUT CORRESPONDENCE and FOOT REPULSION is essential for our present analysis.
3. With respect to the phonological analysis of the data, we suggest a random ranking of weighed correspondence and markedness constraints. By means of weighing constraints we adopt an OT variant that more or less resembles the analyses in OT's predecessor Harmonic Grammar (cf. Legendre, G., Y. Miyata & P. Smolensky, 1990). Note that we do not opt for a co-phonology for allegro-style speech in our analysis. In a co-phonology, the output of the andante-style ranking is input or base for the allegro-style ranking. We opt for a random ranking with different preferences for allegro and andante speech, because our data show variable rhythmic structures at both rates. Both rankings evaluate the same input form.
4. The perceived loudness depends on the frequency of the tone. The Phon entity is defined using the 1kHz tone and the decibel scale. A pure sinus tone at any frequency with 100 Phon is as loud as a pure tone with 100 dB at 1kHz (Rietveld and Van Heuven 1997: 199). We are most sensitive to frequencies around 3kHz. The hearing threshold rapidly rises around the lower and upper frequency limits, which are respectively about 20Hz and 16kHz.

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