Hunyadi László: Experimental evidence for recursion in prosody
Argumentum, 4 (2008), 266-279
Kossuth Egyetemi Kiadó (Debrecen)

Tanulmány

Hunyadi László

Experimental evidence for recursion in prosody[1]

Abstract

It is widely assumed that mismatches between syntactic and prosodic structure are mainly due to the fact that they represent two, principally different kinds of structure. Namely, whereas syntactic structure has an indefinite depth generated by recursion, prosodic structure is flatter owing to the lack of this generative power. This article argues that in some essential aspects prosody is also recursive. Namely, it is based on recursive grouping in the form of recursive embedding expressed by such prosodic principles as *inherent grouping* and *tonal continuity*. The article presents these principles supported by a series of production and perception experiments.

1 Introduction

In their 2002 article in *Science* Hauser, Chomsky and Fitch (Hauser, Chomsky & Fitch 2002) return to one of the central issues in generative grammar: the nature of the faculty of language. In their understanding this notion is narrowed down to the sole computational mechanism of recursion that underlies the massive generative capacity of human language. They point out that, even though there are further instances of recursion in humans, such as the systems of orientation or numbering, linguistic recursion has come about independently from them. As for language, they assume that recursion is limited to syntax alone. Accordingly, morphology or phonology, although part of linguistic structure, are not to be considered recursive.

One of the strongest arguments they develop is that the faculty of language, being restricted to the computational mechanism of recursion, is to be strictly distinguished from communication, i.e. it did not evolve for purposes of communication. Furthermore, it is considered uniquely human, and, as such, it cannot be the result of human evolution.

These arguments, whose purpose, admittedly, was to encourage further research into these fundamental issues of the nature, structure and evolution of human language and its relation to other human cognitive systems as well as comparable faculties in non-humans, has indeed opened way to important and far-reaching discussions and research (cf., among others, Jackendoff and Pinker 2005, Pinker and Jackendoff 2005). Although we are far from seeing the resolution of these fundamental questions, the debates have lead to a better understanding

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of the form, extent and limitations of recursion in human language (cf. an extensive discussion of the issue in Parker 2006). In what follows we will examine if and how recursion can be present in prosody.

2 Recursion in prosody?

In their above article Hauser, Chomsky and Fitch refer to prosody as one of the levels of human language where recursion is not present. Apparently, it has been long believed that one of the fundamental differences between syntax and prosody is that, whereas syntax has an unlimited depth due to its recursive component, prosody is flatter due to the lack of recursion (cf. Selkirk (1984) and her Strict Layer Hypothesis). Although further observations have resulted in allowing for some limited recursion in prosody (cf. Ladd's (1986, 1996) Compound Prosodic Domain and Selkirk's 1995, Coper & Cooper 1980, Truckenbrodt & Hubert 1999, 2007, Clifton, Carlson & Frazier 2002), but these limitations did not fundamentally change the established view and they were directly reflected in Hauser, Chomsky and Fitch's article as well.

At the same time, however, it has also been shown that two major components of prosody, i.e. duration and pitch (F0) movement show recursive features. It was shown in Wagner (2006) that variation in duration is a significant prosodic means of representing syntactic recursion. In Hunyadi (2006) and Hunyadi (forthcoming), on the other hand, prosody was placed in a wider perspective. Accordingly, both duration and pitch variation show patterns of recursion and correspond to recursion in syntax. Furthermore, it is shown that the fundamental principles of prosodic recursion are not unique to language but can be found in grouping across other human modalities.

3 Principles of the expression of recursion in prosody

According to Hunyadi (*ibid.*), recursion has the following main principles in prosody:

a) Recursion operates on *groups*.
b) *Grouping is denoted by both duration and pitch*. As for duration, pauses between elements inside a group are shorter than between groups. As for pitch, elements within a single group are joined by a single continuous pattern of tonal excursion, whereas elements belonging to two different groups are represented by a boundary made of tones of opposite direction of pitch movement.
c) In speech prosody, *pitch is primary to duration*. Accordingly, grouping (the belonging of elements to one and the same or to different groups) is always denoted by pitch (tonal) variation, whereas the quantity of pauses may not strictly follow the structure denoted by pitch movement.
d) *Grouping is inherent*. Accordingly, by means of prosody, more than two elements are separated into groups even if such a grouping is not present in the structural description of such elements. As such, an unstructured sequence of, say, four elements of arbitrary form is prosodically divided into two equal groups either by two separate tonal contours alone or by two separate tonal contours and two separate rhythmic units.

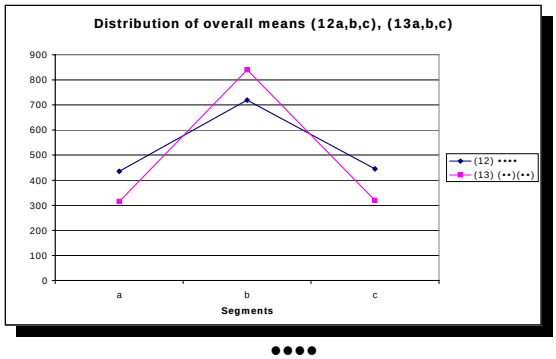
e) The structural embedding of elements is prosodically expressed by *tonal embedding* (and, optionally, by duration as well). Recursive embedding is expressed by recursive tonal embedding.
f) The structural unity of discontinuous elements is denoted by *tonal continuity*. Accordingly, regardless of how far two segments of a larger unit are displaced, they form a virtual (discontinuous) tonal unit, overcoming the effect of downdrift.

These principles are assumed to be part of the system of rules prosody is made of and are expected to be present in actual speech production. However, due to the robust nature of language, certain functions are expressed by more than one subsystem which may compete in prominence. Similarly to the fact that, competing for the expression of grouping, pitch movement has (non-exclusive) prominence over duration, syntax may also appear to have prominence over prosody. Accordingly, we may expect that certain non-fulfillment of proper prosodic grouping would not lead to the perception of the violation of grammaticality.

In what follows, we will present the results of experiments testing the validity of the last three principles. First, we will see if grouping is inherent in unstructured groups with more than four elements. Next, we will find out if the direction as well as frequency limits of pitch movement have a significance in the perception of tonal embedding. Finally, we will test the role of pitch variation in the perception of tonal continuity.

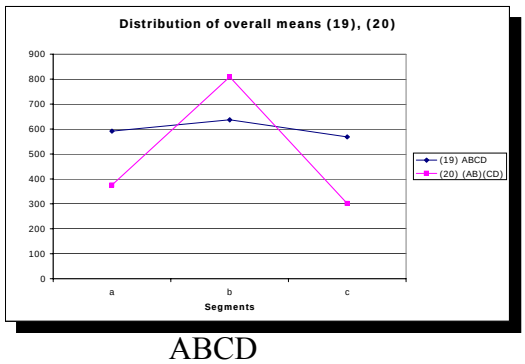
4 Grouping is inherent

As it has been shown in Hunyadi (*ibid.*), a sequence of four elements is divided by a pause into two rhythmic groups both when they are unstructured and when grouping is specifically denoted. Two kinds of experiments were carried out: a) subjects were presented with two series four dots: •••• and (••) (••) and to represent these grouping patterns with mouse clicks; b) subjects were presented with two series four letters: ABCD and (AB) (CD) and asked to pronounce the names of these letters following the grouping patterns they observe. The results are shown in Figure 1 and Figure 2:



••••
(••)(••)

Figure 1



ABCD
(AB)(CD)

Figure 2

As the above figures demonstrate, a clear temporal grouping was performed in the case of patterns with structured (visually indicated) grouping, however, to a lesser degree, such a

temporal grouping was also observed when no such grouping was marked. There was also some quantitative difference between patterns with abstract visual and abstract prosodic patterns indicating that, with prosodic patterns, duration is secondary to pitch variation.

In what follows, we will demonstrate results of an experiment in which we wished to find out if inherent grouping could also be observed in sets of other than four elements. Subjects were asked to use mouse clicks to represent each of the dots in sets of three to nine dots. No structure was visually presented. Each of the following charts indicates the rhythmic grouping within the given patterns based on the average duration of pauses between two adjacent dots (accordingly, the number of columns for each pattern is one column less than the number of dots in the given pattern):

3 dots: 2 + 1
4 dots: 2 + 2
5 dots: 2 + 2 + 1
6 dots: 3 + 2 + 1
7 dots: 3 + 3 + 1
8 dots: 3 + 3 + 2
9 dots: 4 + 3 + 2

Using paired one-tail t-t-test, responses across pattern types were all significant at $p < 0.5$ or better. As the charts show, grouping is present in all patterns, i.e., instead of equal spacing (as the lack of any structural marking would suggest) the dots are represented in a fairly regular rhythm. From 5 dots onwards there are three groups in each pattern with the first group tending to have the greatest number of elements. It can also be noticed that the first group in each pattern has close to half of the total number of elements. Accordingly, in larger patterns we notice a recursive grouping: the first group represents approximately half of the elements and the second half is again nearly halved into two groups, again the first group being slightly numerous that the following one. (As a matter of fact, this continuously decreasing number of elements in consecutive groups is akin to the continuous shortening of pauses between recursively embedded elements, observed in embedded sentence clauses as well. This obvious similarity between seemingly non-related objects – dots and clauses – in similar (recursively embedding) structures can serve as the indication of a general, universal property of recursion across modalities.)

5 Tonal patterns of grouping: embedding and tonal continuity

It was shown in Hunyadi (*ibid.*) that boundaries between groups including abstract prosodic elements such as A, B, C, D are denoted by tonal grouping: the tones separating two groups have an opposite direction or opposite level. Accordingly, the pattern

(AB) (CD)
(fall + rise) (fall + fall) or
(high level + high level) + (low level + low level)

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It was also shown that syntactic embedding has its prosodic counterpart as well: an embedded segment (such as a clause) receives a lower tonal contour following the principle of *tonal embedding*.

In addition, it was also shown that there exists a special tonal relation between discontinuous segments separated by an embedding as well as insertion, that of *tonal continuity*. According to tonal continuity, the two discontinuous segments form a virtual tonal unit, despite the usual effect of downdrift in speech. Cf. (1):

(1) A macska, amit a kutya, ami megveszett, megharapott, elszaladt.
'The cat that the dog that was rabied, bit, ran away.'

The tonal contour of this sentence with multiple embedding is shown as (1'), Figure 3:

(1')

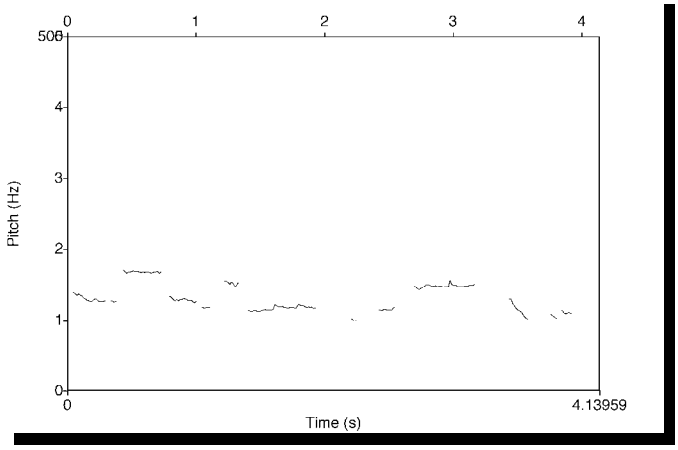

Figure 3

The above pitch contour demonstrates that tonal embedding is in effect. Removing the innermost embedding demonstrates the effect of tonal continuity, cf. (1a) and (1a'):

(1a) A macska, amit a kutya [...] megharapott, elszaladt.
'The cat that the dog [...] bit, ran away.'

(1a')

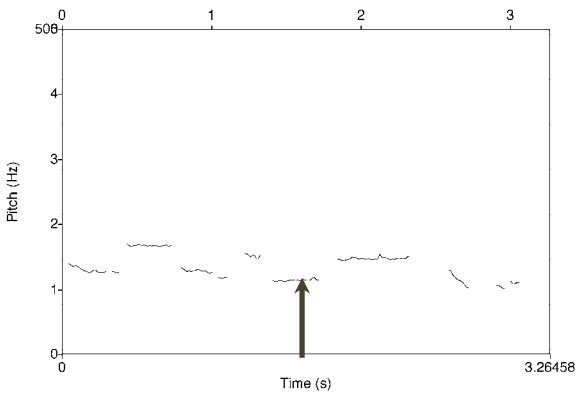

Figure 4

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As the arrow at the location of the removal of the embedding shows, the tone of the now joined, originally discontinuous two segments remains the same with no effect of downdrift.

Removing yet another embedding, (1b) demonstrates that tonal continuity operates on longer distances as well, cf.:

(1b) A macska [...] [...] elszaladt.
'The cat [...] [...] ran away.'

(1b')

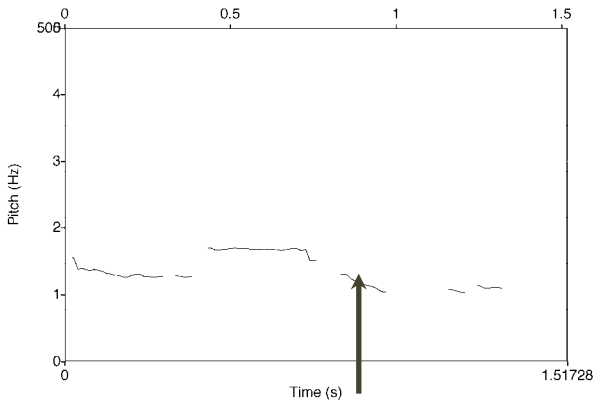

Figure 5

The principle of tonal continuity for discontinuous segments can also be observed in insertion, cf. (2):

(2) Meg tudnád mondani, hogy – az én órám megállt – hány óra van?
'Could you tell me – my watch has stopped – what time it is?'

(2')

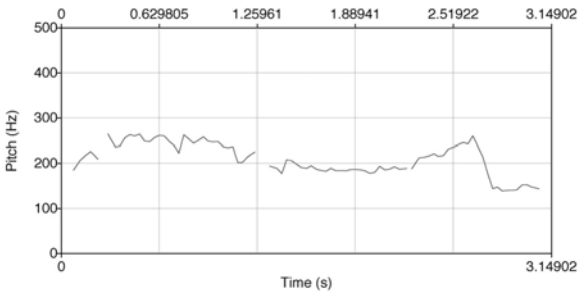

Figure 6

Removing the inserted clause we get (2a):

(2a) Meg tudnád mondani, hogy [...] hány óra van?
'Could you tell me [...] what time it is?'

(2a')

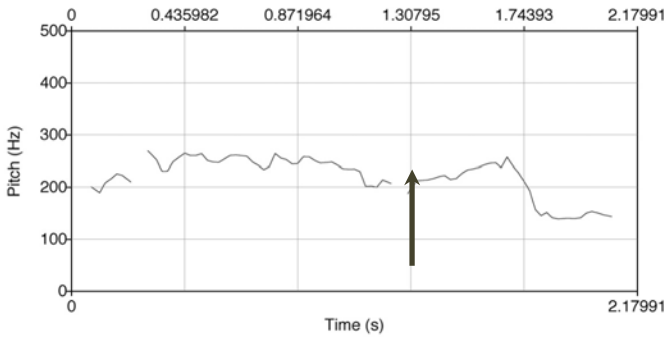

Figure 7

Tonal embedding as well as tonal continuity were observed in a number of recordings and across languages other than Hungarian as well thus suggesting that these principles are in effect in actual speech production in general. However, due to the fact that embedding and insertion are essentially syntactic by nature with their syntactic means of expression, one may ask how redundant their tonal counterparts can be. Accordingly, we can ask the question to what extent the violation of these prosodic principles can be considered as a rule violation in perception. In what follows, we will present the results of three experiments to address this issue.

6 Perception experiment 1: the violation of the position of tone in the expression of prosodic grouping

20 university students were presented with three sentences including an embedded clause. In addition to the original recordings, they were presented such versions in which either the embedded clause (denoted as "a") or the second, discontinuous part of the main clause (denoted as "b") had its tone modified, lowered or raised. After initial pilot experiments it was decided that the steps of modification would be fairly large, 50, 100 or 150 Hz. The sentences involved were as follows:

(3) A tanuló, aki kimerült, mérges volt.
'The student that was exhausted, was angry.'

(4) A tanárnő, aki fellépett, kicsi volt.
'The teacher who made her appearance, was small.'

(5) A kisgyerek, aki visszament, komoly volt.
The little child who returned, was serious.

In order to ensure that listeners would consider the sequences of clauses with the second one embedded rather than as conjunction, the sentences were chosen so that there would essentially be no semantic or pragmatic relation between the constituting clauses.

The tonal variations were produced in the computer program Praat and the experiment was carried out using the program PsyScope. The following patterns were involved (the above

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numbering of sentences (3), (4) and (5) corresponds to 1., 2. and 3., respectively, in the experiment:

1. 1 (no manipulation)
2. 2 (no manipulation)
3. 3 (no manipulation)
4. 1.c.lowered-50
5. 2.c.lowered-50
6. 3.c.lowered-50
7. 1.c.raised+150
8. 2.c.raised+150
9. 3.c.raised+150
10. 1.c.lowered-100
11. 2.c.lowered-100
12. 3.c.lowered-100
13. 1.c.raised+50
14. 2.c.raised+50
15. 3.c.raised+50
16. 1.c.raised+100
17. 2.c.raised+100
18. 3.c.raised+100
19. 1.b.lowered-50
20. 2.b.lowered-50
21. 3.b.lowered-50
22. 1.b.lowered-100
23. 2.b.lowered-100
24. 2.b.lowered-100
25. 1.b.raised+50
26. 2.b.raised+50
27. 3.b.raised+50
28. 1.b.raised+100
29. 2.b.raised+100
30. 3.b.raised+100
31. 1.b.raised+150
32. 2.b.raised+150
33. 3.b.raised+150

Subjects were asked to give a goodness judgement of each of the tonal variations on a 6-button scale (6 = most accepted, 1 = least accepted).

Based on the calculated average values, we got the following results:

Goodness judgements of pitch manipulations

Using paired one-tail t-t-test, responses across pattern types were all significant at $p < 0.5$ or better. The responses clearly made a distinction between the patterns depending on which segment was manipulated. The least unacceptable were those patterns where segment “c”, i.e. the one following embedding was manipulated. On the other hand, if the embedded segment

"b" was manipulated, starting from pattern 19, the results were less favorable. But even in this latter respect there were differences: lowering segment "b" was considered less as a violation than raising it. As probably intuitively expected, the extent of lowering or raising "b" (by 50 or 100 Hz) was also a factor in accepting/rejecting the given pattern.

Since both tonal embedding (observed in segment "b") and tonal continuity (observed in segment "c") are considered basic principles of prosodic grouping, we need to account for the fact that manipulating segment "c" (i.e. violating tonal continuity) received better goodness judgements than manipulating segment "b" (i.e. violating tonal embedding). As for tonal embedding, we see that raising segment "b" is considered as more significant than lowering it. This observation directly follows from the nature of tonal embedding: lowering the tone of "b" may be perceived as stylistically marked, but the rule itself is not violated: the tone of the embedded clause is lowered. On the other hand, if "b" is raised, in addition to the sense of an obvious stylistic markedness a clear violation of the tonal rule of embedding is also observed thus justifying the lower acceptance of these patterns. As for tonal continuity, the manipulation of segment "c" is less sensitive to goodness judgements for the following reason: if the principle of tonal continuity is not observed, the boundary between segment "b" and segment "c" is still denoted by two additional prosodic means: the right edge of "b" having a rising tone (thus denoting a right group boundary) – an obligatory prosodic marking – and the pause following it (optionally denoting the same right group boundary). As a result, the manipulation of the pitch of "c", whether its lowering or raising, does not leave the sequence of clauses without prosodic marking, and its manipulation can freely be used (and is indeed used) for stylistic purposes.

Along with this broad picture of the relation between syntactic structure and prosodic (tonal) variation we note here two additional observations. First, the values representing the standard deviation of the responses is patter dependent: it has a fairly close relation to the degree of goodness. The lesser the degree of goodness, the higher the corresponding values of standard deviation. In all, however, it was only patterns with segment "b" manipulated that were clearly rejected (below score 3, i.e. below 50% of the maximum score). This fact can be considered as a strong support for tonal embedding being a basic principle of prosodic grouping. Second, we can observe a difference between the goodness judgements of the three sample sentences, consistent across similar patterns: in almost all cases variants of sentence (1) received lesser scores than (2) and the highest scores were received by (3). Accordingly, it can also be suggested that factors outside prosody (including semantics) also play a role in the degree of acceptance.

7 Perception experiment 2: the role of the tonal manipulation of the accented syllable in the expression of prosodic grouping – goodness judgements

In the previous experiment the tone of segments "b" or "c" was lowered or raised in their entirety. It had the effect that, in certain cases, the final pitch of a segment, that would normally be at least close to the baseline, was also raised, thus producing a less natural sounding already by itself. Therefore, we designed an additional experiment in which only the accented syllable of the given segments (the actual starting point and principal marker of tonal movement, including embedding) was manipulated. Based on the results of the previous experiment showing that further lowering the tone of an embedded clause is less of a sign of rule violation, we were interested in whether raising the corresponding accented syllables has

an effect on goodness judgements. We included three sentence patterns each with recursive embedding, cf. (6), (7) and (8):

(6) A levél, amit Kati, aki boldog volt, feladott, elveszett.
'The letter, that Kate, who was happy, posted, got lost.'

(7) A macska, amit a kutya, a mi megveszett, megharapott, elszaladt.
'The cat, that the dog, that was rabid, bit, ran away.'

(8) A madár, amit a vadász, aki ittas volt, megcélzott, elrepült.
'The bird, that the hunter, that was drunk, aimed at, flew away.'

The subjects involved in the experiment were 25 university students who were asked to give a goodness judgement of each of the tonal variations of the above sample sentences – 15 in all – on a 6-button scale (6 = most accepted, 1 = least accepted).

The tonal variations were produced in the computer program Praat and the experiment was carried out using the program PsyScope. The following patterns were involved (the above numbering of sentences (6), (7) and (8) corresponds to 1., 2. and 3., respectively, in the experiment, all affecting the embedded segments "b" and "c":

1: (6) no manipulation
2. (6).b raised to a
3. (6).b raised to a and c raised to a
4. (6).c raised to a
5. (6).c raised to b
6. (7) no manipulation
7. (7).b raised to a
8. (7).b raised to a and c raised to a
9. (7).c raised to b
10. (7).c raised to a
11. (8) no manipulation
12. (8).b raised to a
13. (8).b raised to a and c raised to a
14. (8).c raised to a
15. (8). c raised to b

Using paired one-tail t-t-test, responses across pattern types were all significant at $p < 0.5$ or better. As shown in the list, each sentence was represented by four variants: one was left without manipulation, another had segment "b" raised to the high pitch of "a", a third had segment "c" raised to the high pitch of "a" while segment "b" was left unmodified (and, following tonal embedding, its tone was lower than that of "a"), and a fourth one had both segment "b" and segment "c" raised to the high pitch of "a".

Based on the calculated average values, we got the following results:

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Goodness judgements of pitch manipulations – 2.

Compared to the results of the previous experiment, we can notice two apparent differences: in this new experiment almost all judgements are positive (above the average score 3) and, as the corresponding values of standard deviation show, there is a significant variation of scores within each pattern. For some reason, even the unmanipulated patterns did not receive a high value (the maximum was around 4 at most, but far from reaching at least a more preferable 5). Two patterns stand somewhat out as the most preferred ones: 11. with no manipulation and 7. with the accented syllable of "b" raised to the high pitch of "a". Even 3., 8. and 13. with no tonal embedding at all are not rejected. It is this relative uniformity of vacillation between acceptance and rejection that the high values of standard deviation are based upon.

However, this relative uniformity of judgements suggests something important: since none of the manipulations affected the baseline of the given segments, at least from this point of view the patterns were perceived as relatively natural. Accordingly, the violation of tonal embedding at the left edge of a segment is successfully counterbalanced by the proper placement of the right edge of the same segment on the baseline. This experiment shows, as a consequence, that what matters in tonal embedding is the narrowing of the tonal space by lowering the starting pitch only and not the lowering of the whole tonal contour of the embedded segment (the latter is the reason why certain patterns were clearly rejected in the previous, first experiment.

Even though the goodness judgements showed a certain degree of undecidedness, still, these patterns gave the chance to find an indirect support for the status of tonal embedding as a valid prosodic principle. Namely, when presented with a sentence of the pattern type 13. with the accented syllable of both embedded segments "b" and "c" raised to the high pitch of "a" subjects were asked to determine which of these peaks is the highest (actually all the three were at the same level), there was a uniform answer: all subjects perceived "c" as the highest with "b" the next highest and "a" the lowest. However surprising as it may be, there is a straightforward account for this judgement. Since the embedding of "b" in "a", and the embedding of "c" in "b" are syntactically denoted, the listener expects (and predicts) the corresponding tonal embedding as well. Since it is the case of recursive embedding, the pitch of "c" equal to that of "b" is perceived as "higher" than that of "b". Also, since "b" is syntactically embedded in "a", "b" is expected to be tonally embedded in "a" as well. Since it does not happen, the pitch of "b" equal to that of "a" is perceived as higher than "a". This striking perception of equal pitches as non-equal is an apparent proof of recursive tonal embedding in prosody.

8 Perception experiment 3: the role of the tonal manipulation of the accented syllable in the expression of prosodic grouping - same vs. different

Finally, we wished to have yet another look at the same sentence patterns but using them in a same vs. different experiment. The justification for such an experiment is that the question the subjects have to decide is much simpler, whereas it allows for determining if a certain rule of principle (such as that of tonal embedding) is a valid one.

There were 23 university students who were asked to determine if, within a pair of utterances, the two recordings are the same or different. The same patterns were used as in the previous experiment so that, within each of the pairs, one of the recordings was unmanipulated

and the other was manipulated. It was expected that same/different judgements would lead to the validation of the principle of tonal embedding. The 12 pairs of patterns were as follows:

1: (6) no manipulation vs. (6).b raised to a
2. (6) no manipulation vs. (6).b raised to a and c raised to a
3. (6) no manipulation vs. (6).c raised to a
4. (6) no manipulation vs. (6).c raised to b
5. (7) no manipulation vs. (7).b raised to a
6. (7) no manipulation vs. (7).b raised to a and c raised to a
7. (7) no manipulation vs. (7).c raised to a
8. (7) no manipulation vs. (7).c raised to b
9. (8) no manipulation vs. (8).b raised to a
10. (8) no manipulation vs. (8).b raised to a and c raised to a
11. (8) no manipulation vs. (8).c raised to a
12. (8) no manipulation vs. (8). c raised to b

Based on the calculated average values, we got the following results:

Goodness judgements of pitch manipulations – 3.

Using paired one-tail t-t-test, responses across pattern types were all significant at $p < 0.5$ or better. As a matter of fact, each pair consisted of an unmanipulated and a manipulated pattern. From the chart we can see that the most apparent difference within the pairs was observed when the manipulated pattern was either manipulated both in "b" and "c" (both raised to the high pitch of "a", as in 2. and 6. – but not in the similar pattern 10., or when "c" alone was raised to the high pitch of "a", as in 3., 7., but not in 11. The least difference was found when "b" was raised to the high pitch of "a". From these data we can conclude, similarly to the conclusion in Experiment 2, that based on data from syntax one expects tonal embedding where syntactic embedding occurs, and one perceives the violation of tonal embedding when it is already too obvious not to notice. Accordingly, it "c" is raised to the high pitch of "a", it strongly violates tonal embedding: instead of being at a pitch level lower than "b", it is higher than that, at the pitch level of "a". Alternatively, when "c" is at its expected place but "b" is raised to the level of "a", tonal embedding is not observed for "b" (but at least it does not take an opposite direction), whereas it is for "c". At the same time, seeing that the tonal patterns of sentence (8) behaves somewhat differently from the two other sentences, it is suggested, yet again, that non-prosodic (among others semantic) criteria also influence judgements.

9 Summary

In this paper we re-examined the results of experiments by Hunyadi (2006) and Hunyadi (forthcoming) from the point of view of the validity of important principles of prosodic grouping and recursion. Results of a production experiment confirmed and extended the validity of the principle of inherent grouping: it was shown that grouping is inherent beyond an unstructured set of four elements. Accordingly, in larger sets one tends to apply inherent grouping recursively: the first boundary is around the half of the pattern and the remaining half is again halved. As an important property it was also found that this recursive inherent

grouping follows the same principle as recursive embedding: the durational boundaries within recursively embedded segments tends to be recursively shorter than the immediately higher ones. Furthermore, experiments were carried out to find out the perceptual validity of the principles of tonal embedding and tonal continuity, both associated with embedding and recursion. It was found that, whereas these principles appear to be present in speech production across speakers and languages, their violation may, under certain conditions, be left unnoticed in perception. The main reason is that in the process of perception we essentially rely on data from syntax and make predictions on the corresponding prosodic realization. It is only the more significant violations that will show up in perception as confronting our predictions. Importantly, the perception of violations is also a strong indication of the existence of these fundamental prosodic principles. Finally, the fact that we found additional, direct and indirect cases of recursion in prosody, can be considered as yet another contribution to the debate on recursion in human language as well as on its evolution.

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