5 The learnability of grammatical stress and weight in Pintupi[37]

5.1 Introduction

It is often taken for granted that normally developing children acquiring one and the same language end up with one and the same grammar (e.g. Chomsky & Halle 1968:251). The language-acquiring child is supposed to be capable of creating the adult grammar from the information provided in the speech stream, despite the fact that this information may be incomplete in terms of possible ambiguities or gaps in the data she is exposed to (known as the *poverty of the stimulus* problem; Chomsky 1986:7). In the computer simulations of acquisition here it is shown that final grammars of virtual learners can differ even though they have been trained on the same data and have the same output as given in the training data. This is demonstrated by modelling the word stress pattern of Pintupi, a language spoken in Western Australia (Hansen & Hansen 1969). The learning algorithms applied in the computer simulations are once again Constraint Demotion (CD; Tesar 1995) and the Gradual Learning Algorithm (GLA; Boersma 1997).

The chapter is built up as follows: section 5.2 outlines Pintupi word stress and provides two possible Optimality Theoretic analyses. Section 5.3 outlines the learnability approach for Pintupi. Section 5.4 gives the ingredients to the computer simulations (the training data, GEN, and the constraint sets). Sections 5.5 and 5.6 discuss the resulting grammars of the learners. Section 5.7 discusses the results of a control group, followed by a general discussion of the results in section 5.8 and concluding remarks in section 5.9.

[37] I thank two anonymous reviewers of a paper version of this chapter originally submitted to Lingua. This chapter greatly benefited from their comments. Needless to say, any remaining errors are my own.

5.2 Pintupi stress

Pintupi (Western Australia; Hansen & Hansen 1969) was chosen as the target language for the computer simulations because of its very regular and predictable stress pattern. Primary stress is on the first syllable in a word and secondary stress is on every other following syllable except if that syllable is final in the word.[38] Syllables can have the shape CV, CVC, CVV, or CVVC, where ‘C’ stands for a consonant, ‘V’ for a vowel, and ‘VV’ for a long vowel. Pintupi has a phonemic vowel length distinction, restricted to the initial syllable of a word. According to Hayes (1991, 1995) and Kager (1992), Pintupi has a bimoraic word minimum. This indicates that Pintupi is a mora-counting language where long vowels are linked to two moras and short vowels are linked to one mora. Pleading for a weight-sensitive stress assignment in Pintupi is the fact that long vowels only occur word-initially; however, the fact that secondary stress is assigned on every other syllable, and not on the syllable directly following the primarily stressed one, is taken here as the cue that stress is not sensitive to weight.

Traditionally, a stress pattern like the one in Pintupi is analyzed with syllabic trochees iterating from left to right, starting at the left word edge (Hayes 1995, Kager 1999). Final syllables in words with an odd number of syllables are unfooted; this could be due to a prohibition of degenerate feet (feet that contain only one mora or syllable; Prince 1980, Hayes 1995:102).

Some examples are listed in (104) with the corresponding syllable and foot structure. The first column lists some examples of Pintupi in an overt-form fashion. These overt forms (displayed in square brackets) include primary stress (‘v́’, where ‘v’ stands for a vowel), secondary stress (‘v̀’), syllable boundaries (‘.’), and vowel length (‘ː’). In the second column the overt forms have been interpreted in terms of hidden metrical structure. These surface forms contain foot structure as well as syllable boundaries (‘.’), the head syllable of the head foot (‘v́’), and the head syllable of a non-head foot (‘v̀’). Long vowels are interpreted as ‘vv’.[39]

[38] Auditory cues for primary stress in Pintupi are loudness, often along with higher pitch and greater duration of syllables; the auditory cue for secondary stress is slightly increased loudness (Hansen & Hansen 1969).

[39] I chose for a representation of small letters for CV structure in order to be able to indicate stresses in a readable form.

(104) Stress and foot structure in Pintupi

Overt forms	Surface forms	
a. [tʲáː]	/(cv́v)/	'mouth'
b. [mú.ŋu]	/(cv́.cv)/	'orphan'
c. [múː.ŋu]	/(cv́v.cv)/	'fly'
d. [tʲán.pa]	/(cv́c.cv)/	'evil spirit'
e. [ká.pa.li]	/(cv́.cv) cv/	'mother's mother'
f. [míːlʲ.ma.nu]	/(cv́v) cv.cv/	'whining'
g. [ŋál.ku.nìn.pa]	/(cv́c.cv)(cv̀c.cv)/	'eating'
h. [pú.ɭiŋ.kà.la.tʲu]	/(cv́.cvc)(cv̀.cv) cv/	'we (sat) on the hill'
i. [tʲá.mu.lìm.pa.tʲùŋ.ku]	/(cv́.cv)(cv̀c.cv)(cv̀c.cv)/	'our relation'

5.2.1 Pintupi stress: two possible OT accounts

Analysing the Pintupi stress pattern in Optimality Theoretic terms[40] requires basically the same constraints as in (14) of section 2.5: constraints on foot structure (PARSE, FTBIN), on foot form (TROCHAIC, IAMBIC), and alignment constraints (AFL/AFR, MAIN-L/R), listed in (105).

(105) Constraints

AFL/AFR: The left/right edge of a foot is aligned with the left/right edge of a word.
FTBIN: Feet are either bimoraic or disyllabic.
IAMBIC: The rightmost syllable in a foot is the head syllable.
MAIN-L/R: The head foot is aligned with the left/right edge of the word.
PARSE: Every syllable is included in a foot.
TROCHAIC: The leftmost syllable in a foot is the head syllable.

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[40] The present OT analysis of Pintupi stress differs slightly from the one by Kager (1999:300) because I include constraints on foot form (TROCHAIC and IAMBIC), and constraints for weight-sensitivity. Kager's account of the learnability of Pintupi stress (1999:301ff.) involves learning from surface forms instead of learning from overt forms. As outlined in section 3.7, I consider this as informed learning. Since it does not reflect a realistic learning situation I do not want to perpetuate it and rather model the learnability of Pintupi stress from overt forms only.

Let us evaluate the ranking for Pintupi stress step by step, starting with a trisyllabic word *kápali* 'mother's mother', as in tableau (106). The underlying form as the input to the evaluation is given in the upper left cell. TROCHAIC is assigned a violation mark by right-headed binary feet, e.g. */(ka.pá) li/, while IAMBIC is assigned a violation mark by left-headed binary feet, e.g. */(ká.pa) li/. Since the language has a strong-weak pattern, TROCHAIC has to outrank IAMBIC; otherwise the grammar would render */(kapá) li/ instead of /(kápa) li/.

(106) *kapali*: TROCHAIC >> IAMBIC

| ka.pa.li |	TROCHAIC	IAMBIC
☞ a. /(ká.pa) li/		*
b. /(ka.pá) li/	*!	

Tableau (107) shows that FTBIN has to be ranked above PARSE. Otherwise the grammar would yield */(kápa)(lì)/ or */(ká)(pà)(lì)/ or /(ká.pa.li)/[41] instead of /(kápa) li/. PARSE is assigned a violation mark once for every syllable not included in a foot, e.g. */ka (pá.li)/. FTBIN is assigned a violation mark by feet with only one mora, e.g. in the final foot of */(ká.pa)(lì)/.

(107) *kapali*: FTBIN >> PARSE

| ka.pa.li |	FTBIN	PARSE
☞ a. /(ká.pa) li/		*
b. /(ká.pa)(lì)/	*!	
c. /(ká)(pà)(lì)/	*!**	
d. /(ká.pa.li)/	*	

Turning to quadrisyllabic words like *ŋalkuninpa* in (108), we can establish the ranking of MAIN-L >> MAIN-R, to make sure that the left foot in a word is the head foot. MAIN-L and MAIN-R are assigned one violation mark for every syllable between the head foot and the respective word edge.

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41 Feet of the size of three syllables or more are banned from GEN in the simulations in section 5.4.

MAIN-L is therefore violated twice in */(ŋàl.ku)(nín.pa)/; MAIN-R is violated twice in /(ŋál.ku)(nìn.pa)/.

(108) *ŋalkuninpa*: MAIN-L >> MAIN-R

| ŋal.ku.nin.pa |	MAIN-L	MAIN-R
☞ a. / (ŋál.ku)(nìn.pa) /		**
b. / (ŋàl.ku)(nín.pa) /	*!*	

PARSE has to be ranked above AFL and AFR in order to allow more than one foot in the word, since AFL and AFR not only cause feet to be aligned with a word edge, but they also favour forms with as few feet as possible. If e.g. AFL outranked PARSE, */(ŋál.ku) nin.pa/ would surface instead of /(ŋál.ku)(nìn.pa)/.

(109) *ŋalkuninpa*: PARSE >> AFL, AFR

| ŋal.ku.nin.pa |	PARSE	AFL	AFR
a. /(ŋál.ku) nin.pa/	*!*		**
b. /ŋal.ku (nín.pa)/	*!*	**	
c. /ŋal (kú.nin) pa/	*!*	*	*
☞ d. /(ŋál.ku)(nìn.pa)/		**	**
e. /(ŋál.ku)(nìn) pa/	*!	**	**

To ensure that feet are built from left to right, AFL has to outrank AFR. The reverse ranking would render */(pú.ɭiŋ) ka (là.tʲu)/[42] instead of /(pú.ɭiŋ)(kà.la) tʲu/. AFL and AFR are gradient and assigned a violation mark for every syllable that is between a foot and the designated word edge.

[42] This happens to be the stress pattern of Garawa (Furby 1974); Hayes 1995), which is the same as for Pintupi in even-numbered words, but deviates from Pintupi in odd-numbered words in that it skips the third syllable in footing: /(σ́σ) σ (σ̀σ)/. I thank an anonymous reviewer for pointing this out to me.

(110)*puɭiŋkalatʲu*: AFL >> AFR

| pu.ɭiŋ.ka.la.tʲu |	AFL	AFR
a. /pu (ɭíŋ.ka)(là.tʲu)/	***!*	**
☞ b. /(pú.ɭiŋ)(kà.la) tʲu/	**	****
c. /(pú.ɭiŋ) ka (là.tʲu)/	***!	***
d. /pu (ɭìŋ.ka)(lá.tʲu)/	***!*	**

One can argue whether trisyllabic forms in Pintupi are sufficient to determine the directionality of foot assignment, because main stress can be assigned independently in Pintupi. I argue that the learner can find evidence for the ranking between AFL and AFR in trisyllabic forms simply because it is a fact that AFL is *not* violated in the licit trisyllabic form /(ká.pa) li/, and that AFR *is*, as tableau (111) shows.

(111)*kapali*: AFL >> AFR

| ka.pa.li |	AFL	AFR
☞ a. /(ká.pa) li/		*
b. /ka (pá.li)/	*!	

This will have an effect on the ranking of the two constraints in the learning algorithms that I discuss. Sections 5.5 and 5.6 will show whether this evidence is sufficient for the virtual learners to detect the left-to-right directionality in Pintupi.

What one would not expect is that PARSE also has to outrank IAMBIC: if IAMBIC was ranked above PARSE it would kick out the licit candidate /(ŋál.ku)(nìn.pa)/ and leave the decision to the lower ranked constraint AFL, which would decide in favour of candidate */(ŋál.ku) nin.pa/. Note that candidate (104e) is ruled out by higher-ranked FTBIN: I assume for the moment that coda consonants are not moraic in Pintupi, rendering a syllable such as *-nin-* as monomoraic and therefore light. As shown in (107), monomoraic feet violate FTBIN.

(112) *ŋalkuninpa*: PARSE >> AFL, IAMBIC

| ŋal.ku.nin.pa |	FTBIN	PARSE	AFL	IAMBIC
a. /(ŋál.ku) nin.pa/		*!*		*
b. /ŋal.ku (nín.pa)/		*!*	**	*
c. /ŋal (kú.nin) pa/		*!*	*	*
☞ d. /(ŋál.ku)(nìn.pa)/			**	**
e. /(ŋál.ku)(nìn) pa/	*!	*	**	

So far, I established a suitable partial ranking of the constraints for words with two to five syllables:

(113) Partial rankings:

TROCHAIC, PARSE >> IAMBIC;
MAIN-L >> MAIN-R;
AFL >> AFR;
FTBIN >> PARSE

However, words with a long initial vowel, e.g. *mi:lʲmanu* 'whining', cannot be accounted for with this ranking, because it cannot decide between two licit candidates /(mí:lʲ.ma) nu/ and */(mí:lʲ)(mà.nu)/. The first candidate should win under a syllabic-trochee analysis, while the second candidate should win under a moraic-trochee analysis. The constraint one would regard as competent for the necessary disambiguation, FTBIN, cannot decide between these two candidates because both /(mí:lʲ.ma) nu/ and */(mí:lʲ)(mà.nu)/ satisfy FTBIN, as shown in (114). Note that FTBIN does not prefer a disyllabic foot (σσ) over a monosyllabic, yet bimoraic foot ($\sigma_{\mu\mu}$), but is equally satisfied by both kinds of feet. In our ranking, the decision between these two candidates is passed on to PARSE, which decides in favour of the wrong candidate, */(mí:lʲ)(mà.nu)/:

(114) Long initial vowel

| mi:lʲ.ma.nu |	FTBIN	PARSE	AFL
☹ a. /(mí:lʲ.ma) nu/		*!	
☞ b. /(mí:lʲ)(mà.nu)/			*
| ki:.ki.mi.la.ɳu | 'to kick'			
☹ a. /(kí:ki)(mìla) ɳu/		*!	**
☞ b. /(kí:)(kìmi)(làɳu)/			****

One could think of reversing the ranking between PARSE and AFL, but this would lead to problems with forms like *ŋalkuninpa* in (109) or *puɭiŋkalat^{j}u* in (110). This means that there is no ranking with these constraints that can account for the Pintupi pattern. The source of the problem might be the constraint TROCHAIC. In its current definition TROCHAIC does not decide between the two foot forms (σ́ σ) and (σ́). A possible solution could be to replace TROCHAIC with FTNONFIN (Tesar (1998; repeated from (14) of section 2.6.1), even though this constraint did not work as good as TROCHAIC did in the simulations of chapter 4:

(115)FTNONFIN: The foot head is not final in the foot.

In this form FTNONFIN punishes monosyllabic feet like (σ́), and favours /(mí:l^j.ma) nu/ over */(mí:l^j)(mà.nu)/. As a by-product, FTNONFIN is taking over the function of FTBIN (here, at least), therefore FTBIN is left out of the tableau in (116).[43] To be able to unfold its full power, FTNONFIN has to outrank PARSE:

(116)FTNONFIN instead of TROCHAIC

| mi:l^j.ma.nu |	FTNONFIN	PARSE	AFL
☞ a. /(mí:l^j.ma) nu/		*	
b. /(mí:l^j)(mà.nu)/	*!		*
| ki:.ki.mi.la.ɳu | 'to kick'			
☞ a. /(kí:ki)(mìla) ɳu/		*	**
b. /(kí:)(kìmi)(làɳu)/	*!		****

The crucial ranking is displayed in (117). MAIN-L outranks MAIN-R so that the left foot within a word gets main stress. MAIN-L furthermore outranks AFL and AFR. AFL outranks AFR to ensure that feet are iterated from left to right. FTNONFIN outranks PARSE to make sure that final syllables remain unfooted in words with an odd number of syllables and to make sure that in words beginning with a long vowel the first two syllables are parsed in a foot, as was shown in (116). FTNONFIN and PARSE outrank IAMBIC, because else iambic feet would surface (which is comparable to the

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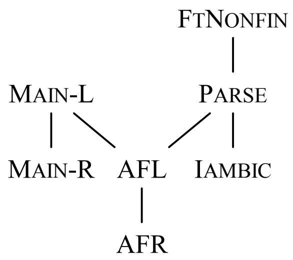
[43] It should be noted that FTBIN can still play a role in other languages that e.g. have an iambic stress pattern.

situation in tableau (106)) or words with only a single foot would surface, as shown in (112).

(117) A crucial ranking for Pintupi stress with FtNonfin[44]



5.2.2 Maintaining an analysis with Trochaic

One could keep up an analysis with Trochaic by including *Clash (Buckley 1998, Kager 1999, Kager 1992; this constraint traces back to pre-OT approaches by Liberman 1975, Liberman & Prince 1977, Prince 1983, Hammond 1984, and Selkirk 1984).[45] This constraint is commonly employed to prevent stresses in adjacent syllables, i.e. clashes:

(118) *Clash: No stressed syllables are adjacent.

If this constraint is included dominating Parse, the attested candidate becomes optimal, as shown in tableau (119).

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[44] It should also be noted that even with FtNonfin undominated, monosyllabic forms are guaranteed to surface through a high-ranking constraint Lx≈Pr (Prince & Smolensky 1993), which entails that content words should be pronounced.

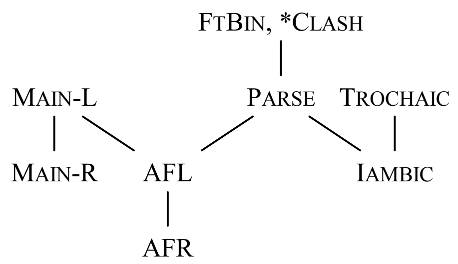
[45] One could also think of keeping up an analysis with Trochaic by splitting up FtBin into FtBisyllabic (“feet are bisyllabic”) and FtBimoraic (“feet are bimoraic”) (similar to Kager 1993a, and later Hewitt 1994, who split up FtBin into FtBimoraic$^{min/max}$, FtBisyllabic$^{min/max}$, and FtBinNuclearMora$^{min/max}$. In Pintupi, FtBisyllabic would then have to outrank FtBimoraic, Trochaic, and Parse, in order to ensure that feet are strictly bisyllabic. While the idea of incorporating FtBimoraic was pursued for the case of Latin, it is abandoned here in favour of an analysis with *Clash, which is independently motivated in a series of other stress phenomena.

(119) An analysis with *CLASH and TROCHAIC

| miːl^j.ma.nu |	TROCHAIC	FTBIN	*CLASH	PARSE
☞ a. /(míːl^j.ma) nu/				*
b. /(míːl^j)(mà.nu)/			*!	

In the crucial ranking including TROCHAIC in figure (120), *CLASH outranks PARSE. For the rest of the analysis, the same crucial rankings apply, as in (117). In a constraint set including FTNONFIN, *CLASH would not play a crucial role and could be placed anywhere in the hierarchy.

(120) A crucial ranking for Pintupi stress with TROCHAIC



By now I have established the analysis for Pintupi word stress with two different constraint sets, one including the constraint FTNONFIN in figure (117) and another with a constraint TROCHAIC in figure (120). It is interesting to see which constraint forms the appropriate restriction on trochaic feet by testing the acquisition process using computer simulations.

5.2.3 The weight of CVC syllables in Pintupi

While long vowels in languages with phonemic vowel length always have two moras (under moraic theory; Hyman 1985, Prince 1976, 1983, Hayes 1989, to name just a few), the moraic status of CVC syllables is not always clear. CVC syllables pattern qua weight with CVV syllables in some languages, while they pattern with CV syllables in others (e.g. Zec 1988). Pintupi is a case where it is not clear whether coda consonants are moraic or not. CVC syllables do not *attract* stress in the sense that CVC syllables are more often stressed than unstressed (which would indicate that they are moraic), but they happen to be stressed sometimes. Other evidence for or against moraicity of codas could come from monosyllabic words. Hansen & Hansen (1978:41) report that there are only very few monosyllabic words in Pintupi, and that they always consist of a CV syllable. They represent syllables with a short vowel and syllables with a long vowel both with CV syllable structure. The few examples Hansen & Hansen (1969) and Hansen & Hansen (1978) provide include monosyllabic function words with short vowels (e.g. *ma* 'direction marker') and even fewer examples of content words with long vowels (e.g. tjaː 'mouth'). Hayes (1991, 1995:103) and Kager (1992) inferred from the data that Pintupi has a bimoraic word minimum, and that the minimal word in Pintupi consists of either two syllables or a syllable with a long vowel. The fact that there are no monosyllabic words in Pintupi with a short vowel and a coda consonant indicates that coda consonants are not moraic, because if they were, monosyllabic words consisting of CVC syllables should be possible. This means that only negative evidence is available for a Pintupi-learning child that coda consonants are not moraic. Under the general assumption that learners can only learn from positive evidence, Pintupi-learning children do not know that there are no monosyllabic words consisting of CVC syllables. Their language has coda consonants, and syllables with coda consonants happen to *sometimes* be stressed, for instance in words like *ŋálkunìnpa*. The decision for moraic or non-moraic codas depends on the ranking of the constraints *Cμ (Broselow et al. 1997), WEIGHT-BY-POSITION (Hayes 1989; Sherer 1994), listed in (121), together with WSP. *Cμ militates against moraic coda consonants, while WBP militates against *non*-moraic coda consonants.

(121) Constraints on coda moraicity

$*C_{\mu}$: Coda consonants are not moraic.
WEIGHT-BY-POSITION (WBP): Coda consonants are moraic.

If *Cμ outranks WBP, coda consonants are not moraic, and the ranking of WSP does not matter (ignoring long vowels for the moment). The decision in tableau (122) is between a candidate with moraic codas, represented with subscript 'μ', and a candidate with codas that are not moraic. The decision is made by high-ranked *Cμ.

(122) Codas not moraic

| ŋal.ku.nin.pa |	*Cμ	WBP	WSP
/(ŋál$_\mu$.ku)(nìn$_\mu$.pa)/	*!		
☞ /(ŋál.ku)(nìn.pa)/		*	

If, however, WBP outranks *Cμ, coda consonants are moraic. If WBP outranks both *Cμ and WSP, all codas surface as moraic:

(123) All codas moraic

| pu.ɭiŋ.kal.pi |	WBP	*Cμ	WSP
☞ /(pú.ɭiŋ$_\mu$)(kàl$_\mu$.pi)/		**	*
/(pú.ɭiŋ)(kàl$_\mu$.pi)/	*!	*	
/(pú.ɭiŋ)(kàl.pi)/	*!*		

If WSP outranks WBP, only codas in stressed syllables surface as moraic. This has an stress-to-weight effect (Myers 1987; Prince 1990), as already stated by Morén (2000):[46]

(124) Stress-to-weight effect

| pu.ɭiŋ.kal.pi |	WSP	WBP	*Cμ
/(pú.ɭiŋ$_\mu$)(kàl$_\mu$.pi)/	*!		**
☞ /(pú.ɭiŋ)(kàl$_\mu$.pi)/		*	*
/(pú.ɭiŋ)(kàl.pi)/		**!	

Equipped with the constraints *Cμ, WBP and WSP as part of the universal constraint set, and given *Freedom of Analysis* (Prince & Smolensky 1993:6, McCarthy & Prince 1993b:21), children can choose between representations with moraic codas, and representations with non-moraic codas. This is tested with the computer simulations in section 5.4.[47]

[46] One feels tempted to discard STRESS-TO-WEIGHT ("if stressed, then heavy"; e.g. Kager 1999) as an independent constraint at this point. However, the ranking of WSP >> WBP >> *Cμ gives the stress-to-weight effect only for coda consonants, and the effect shows not in the case long vowels are involved.

[47] The reason why I do not model the learnability of vowel length and stress here is that this would involve faithfulness to the underlying moraicity of vowels. The topic for this chapter is the learnability of grammatical stress without the involvement of faithfulness. Modelling stress that involves faithfulness is tackled in chapter 6.

In the remainder of this chapter, moraic codas are represented with subscripted 'μ' as in /(ŋál$_{\mu}$.ku)(nìn$_{\mu}$.pa)/, and non-moraic codas as /(ŋál.ku)(nìn.pa)/, without a subscript 'μ'. I assume that vowels in Pintupi are always moraic, and chose not to mark them with 'μ' for readability reasons. We will see in section 5.5 whether my virtual learners found enough evidence in the training data to infer that coda consonants should not be moraic in Pintupi.

5.3 Modelling Pintupi stress

In section 5.2 I established a constraint ranking that accounts for Pintupi stress. Learnability provides a tool for testing the viability of a linguistic analysis. The learnability of metrical structure is intriguing, since the interpretation of stress in the speech stream regarding structure can be ambiguous. If a listener hears a trisyllabic form with stress on the middle syllable like [σ σ́ σ], she might interpret this form as having either an iambic foot /(σ σ́) σ/ or a trochaic foot /σ (σ́ σ)/. Adult speakers of a language ideally know how to interpret the form, based on their knowledge about whether the language is trochaic or iambic, but learners of a language do not know this yet.

The former OT-based simulations on the acquisition of metrical stress demonstrate the learnability from overt forms, i.e. forms that are marked for stress but not for foot structure. The learning data consisted of strings of light ('L') and heavy ('H') syllables, e.g. [L1 L L], [L H1 L], [H H1 L L2].[48] In Pintupi, stress can appear on syllables with coda consonants, giving room for the interpretation that these syllables are heavy and attract stress. But there are also syllables with coda consonants that are unstressed, indicating that these syllables are analyzed as being not heavy since they do not attract stress. It is interesting to see whether virtual learners of Pintupi analyze the language as completely weight-insensitive or as partly weight-sensitive, or even as completely weight-sensitive, because the long vowels in the language occur only word-initially and are always stressed. Long vowels, which are assumed to have two moras, do not shed light on the question

[48] The '1's refer to primary stress, and the '2's refer to secondary stress.

whether Pintupi stresses weight-sensitive or not, because they only occur in the first syllable of a word, which happens to be primarily stressed anyway.

Another question is whether the virtual learners acquire the Pintupi-like stress pattern, i.e. whether they will have primary stress on the initial syllable of the forms and secondary stress on every other following syllable, with the exception of final syllables in words with an odd number of syllables. Whether the learners will choose the foot structure shown in table (104) or whether they will assign feet differently is subordinate to the question whether stress is assigned to the correct syllable of the word. I gave the virtual learners a head start: they know that their language, Pintupi, has weight characteristics in that it has phonemic vowel length.

In section 5.2, two analyses of Pintupi stress were given. They differ in their interpretation of the constraint on trochaicity. To see whether there exists a difference in the learnability of these constraints one half of the virtual learners is equipped with FTNONFIN and the other half is equipped with TROCHAIC. If it turns out that e.g. the learners with FTNONFIN can learn the stress pattern more easily or can learn it at all, and the learners with TROCHAIC fail to learn the pattern it will indicate that TROCHAIC is not a good formulation of the constraint on trochaicity. The same holds for the reverse case where the learners with FTNONFIN fail and the ones with TROCHAIC succeed.

A further issue is how uniform the grammars of the learners are in the final state. If the learners come up with different constraint rankings, they could come up with different foot structure as compared to the ones established in §5.2. It is also interesting to see to what extent the learners are able to transfer the learned stress pattern to forms that they have not encountered up to that point. Finally, one half of the learners has CD (Tesar 1995) as the reranking strategy, while the other half has the GLA (Boersma 1997) to compare the learning performances of both strategies.

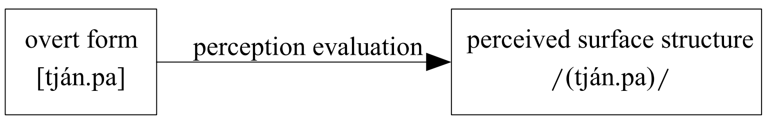
The simulations are carried out with the Praat programme (Boersma & Weenink 1992-2006). The virtual learners created by the programme have to find out for themselves whether coda consonants are moraic or not, and whether stress is sensitive to the weight of a syllable.

The upcoming sections outline the perception process in 5.3.1, the production process in 5.3.2, and the reranking strategies CD (5.3.3) and GLA (5.3.4). The ingredients to the computer simulations are given in section 5.4, followed by the results in section 5.5. The generalizations to forms that the learners have not been trained on are given in section 5.6. The results of a control group are given in section 5.7. A discussion of the results and the conclusions are given in sections 5.8. and 5.9.

5.3.1 Perceiving Pintupi stress

Perception in Pintupi works essentially the same as already demonstrated in sections 3.2 and 4.5, but for the purpose of testing the learnability of coda moraicity I unravelled the L/H syllable structure we saw in the approach to the learnability of Latin stress. The overt forms no longer consist of words with L/H syllable structure, but of words with CV-, CVV, and CVC-syllables. As before, syllable boundaries are given, with the consequence that the learners do not have to find out whether a word-medial consonant belongs to the coda of the preceding syllable or to the onset of the following. Primary stress is indicated by ‘´’, secondary stress by ‘`’. Stresses are given in the overt form, foot structure has to be imposed by the listener.

(125) Perception of Pintupi stress



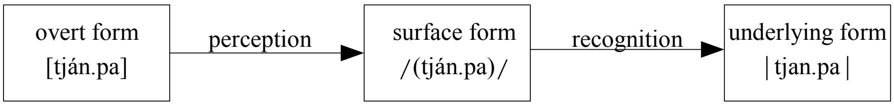
The tableau evaluation of this overt form is shown in (126) with an overt form [t^{j}án.pa]. Consider a Universal Grammar that consists of the constraints PARSE, AFL, AFR, FTBIN, IAMBIC, TROCHAIC, WSP and NONFIN (NONFIN as defined in (14) of section 2.6.1). Imagine that a listener has the grammar in tableau (126). The listener assigns foot structure to the incoming form [t^{j}án.pa] by applying her grammar. Since the overt form already contains stress, the possibilities to assign foot structure are limited, and only two candidates are considered for evaluation. Candidate (117a), /(t^{j}án.pa)/, has a disyllabic foot, while candidate (117b), /(t^{j}án) pa/, has a monosyllabic foot. I assume here that there cannot be a candidate like /(t^{j}an.pá)/ since stress would be on a different syllable. The decision for candidate /(t^{j}án.pa)/, as the optimal one (marked with a ‘ 👂 ’ in the tableau) is taken by high-ranked PARSE. Candidate /(t^{j}án) pa/ violates PARSE, because the final syllable is not footed. Thus, the listener has interpreted the overt form [t^{j}án.pa] as having the structure /(t^{j}án.pa)/.

(126) Perception: stress to foot

[t^{j}án.pa]	PARSE	AFL	AFR	FTBIN	IAMBIC	TROCHAIC
☞ a. /(t^{j}án.pa)/					*	
b. /(t^{j}án) pa/	*!		*	*		

Now that the listener has determined the surface structure /(t^{j}án.pa)/ of the overt input [t^{j}án.pa] she maps this perceived form onto a form in her lexicon. This means for the purposes of this chapter that the surface form is trivially mapped onto the underlying form by stripping off all metrical structure like feet and stress marks, leaving only the segmental and syllabic structure |t^{j}an.pa|.[49] The whole process of perception and recognition is comprehension.

(127) Comprehension



As outlined in §3.2 to 3.6, the comprehension process is the same for adults and language learning children, implying that the learner already knows the underlying form. This will do for the moment, because we deal with grammatically assigned stress only at the moment. However, this is not a realistic learning situation: there are languages that have lexically determined stress, i.e. where stress specifications in the lexicon interact with the grammar (e.g. in Modern Greek of chapter 6). A language learner does not know initially whether the target language has grammatical or lexical stress, and will have to learn the underlying forms as well. Chapter 6 gives an account for the case where the underlying form itself is not given, but has to be created by the learner. For now, it will suffice to assume that the learner knows the underlying forms. In the following section we will see how the learner is able to evaluate her own production by applying her current grammar.

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[49] In real life the acquisition of metrical structure interacts with the acquisition of segmental and syllabic structure and with the creation of lexical entries. Once again these issues are left out of consideration since the discussion here is limited to the acquisition of metrical structure alone.

5.3.2 Virtually producing Pintupi stress

The previous section showed how the learner perceives the overt form [tʲán.pa] as having the surface structure /(tʲán.pa)/. From listening alone the learner will not arrive at an adult-like grammar. She needs to compare her perception to her production in order to be able to learn. Each time she encounters an incoming form, she will compute what she herself would say. In the production evaluation in tableau (128) are more candidates than in the perception evaluation, because the learner has to add foot structure *and* stress to the form.[50] Candidate (119a), /(tʲán.pa)/, is the perceived form of (126) and is marked with '👂'. This perceived form has trochaic foot structure, and is ruled out by IAMBIC. The form that the learner would produce, /(tʲan.pá)/, (marked by '👄') satisfies IAMBIC.

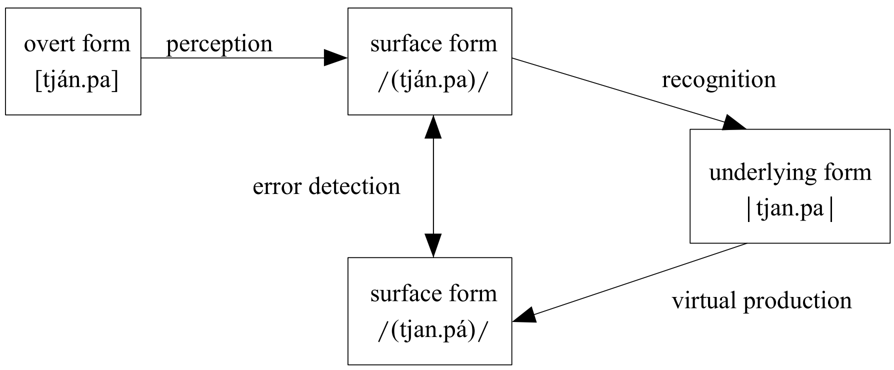
(128) Virtual production: foot to stress

| tʲan.pa |	PARSE	AFL	AFR	FTBIN	IAMBIC	TROCHAIC
👂 a. /(tʲán.pa)/					*!	
b. /(tʲán) pa/	*!		*	*		
c. /(tʲán)(pà)/		*!	*	**		
d. /tʲan (pá)/	*!	*		*		
👄 e. /(tʲan.pá)/						*
f. /(tʲàn)(pá)/		*!	*	**		

Now that the learner computed what she would produce for the form she perceived, she can compare the two forms and notice an error between them. This discrepancy between the perceived form and the produced form impels the learner to change her grammar, until her perceived surface form and her produced surface form are identical.

[50] GEN dictates many more candidates than the ones shown here, but for clarity's sake I stick to just a few of them.

(129) Error detection



Two strategies for constraint reranking are applied in the computer simulations here: Constraint Demotion (Tesar 1995) and the Gradual Learning Algorithm (Boersma 1997). They are outlined in sections 5.3.3 and 5.3.4.

5.3.3 Learning with Constraint Demotion

As mentioned in section 3.4, the learner regards the perceived form as the target she wants to match her production to. When using Constraint Demotion (henceforth CD) as the learning strategy she will adjust her constraint ranking by looking up all constraints that prefer her produced form and lower them below the highest ranked constraint that prefers the form she perceives. This will make it more likely that in a future evaluation of this form, the produced form matches the perceived form. The CD makes use of crucial ties: the violations of all constraints within one stratum are summed up, and the candidate with the least violations in that stratum is the most harmonic one.

In our example learning tableau in (130), IAMBIC is the constraint preferring the learner's produced form /(t^{j}an.pá)/, and TROCHAIC is the constraint preferring the learner's perceived form /(t^{j}án.pa)/. To make it more likely that the perceived form /(t^{j}án.pa)/ will also be the winner of the production evaluation, IAMBIC is demoted below TROCHAIC, into a new stratum:

(130) CD at work in Pintupi

| t^jan.pa |	PARSE	AFL	AFR	FTBIN	IAMBIC	TROCHAIC	
👂 a. /(t^ján.pa)/					*!		
b. /(t^ján) pa/	*!		*	*			
c. /(t^ján)(pà)/		*!	*	**			
d. /t^jan (pá)/	*!	*		*			
👄 e. /(t^jan.pá)/						*	
f. /(t^jàn)(pá)/		*!	*	**			

The next time the learner encounters the form [t^ján.pa], she will still perceive /(t^ján.pa)/, even with the new ranking:

(131) Perception with the new ranking

[t^ján.pa]	PARSE	AFL	AFR	FTBIN	TROCHAIC	IAMBIC
👂 a. /(t^ján.pa)/						*
b. /(t^ján) pa/	*!		*	*		

When computing her production anew, she no longer detects an error:

(132) Production anew

| t^jan.pa |	PARSE	AFL	AFR	FTBIN	TROCHAIC	IAMBIC
👄 👂 a. /(t^ján.pa)/						*
b. /(t^ján) pa/	*!		*	*		
c. /(t^ján)(pà)/		*!	*	**		
d. /t^jan (pá)/	*!	*		*		
e. /(t^jan.pá)/					*!	
f. /(t^jàn)(pá)/		*!	*	**		

In our example, the perceived and produced form have been brought to agreement now; the produced form is identical to the perceived form: /(t^ján.pa)/.

When this happens with all the forms that the learner encounters, learning is terminated. However, it is possible that the reranking of constraints leads to a different interpretation of the same form, which in turn potentially leads to a new mismatch of the interpreted and produced form. The intermediate encounter of other forms might change the constraint ranking in a way that interpretation and production are out of tune again. In general, though, the encounter of different forms should help the learner to come up with a ranking that creates forms matching the adult output.

5.3.4 Learning with the Gradual Learning Algorithm

While CD makes use of an ordinal ranking of constraints, the Gradual Learning Algorithm (henceforth) GLA makes use of Stochastic OT (Boersma 1998), as outlined in section 3.6.2. Constraints are assigned real numbers (*ranking values*) on the ranking scale as a measurement of the distance between constraints. In each evaluation of a given form, a little bit of noise is added to the ranking value of each constraint, with the consequence that constraints close to each other can swap their order for this specific evaluation. In addition to that, grammar adjustment in the GLA is a bit different. In the GLA, all constraints that prefer (i.e. not violated in) the perceived form (IAMBIC) and all constraints that prefer the produced form (TROCHAIC) are looked up. Consider the same grammar as in tableau (128), with the same constraints and ranking, repeated in (133). After realizing that the surface form in perception and the surface form in production do not match, i.e. after detecting an error, the learner adjusts her grammar.

(133) Grammar adjustment with the GLA

| t^jan.pa |	PARSE	AFL	AFR	FTBIN	IAMBIC	TROCHAIC
👂 a. /(t^ján.pa)/					*!→	
b. /(t^ján) pa/	*!		*	*		
c. /(t^ján)(pà)/		*!	*	**		
d. /t^jan (pá)/	*!	*		*		
👄 e. /(t^jan.pá)/						←*
f. /(t^jàn)(pá)/		*!	*	**		

The constraints preferring the perceived form are shifted upwards, while the constraints preferring the produced form are shifted down the hierarchy by a specified amount. Irrespectively of TROCHAIC, IAMBIC is lowered on the ranking scale; irrespectively of IAMBIC, TROCHAIC is shifted up on the ranking scale. The dashed line in (133) reads as a beginning overlap of the two constraints, and the arrows indicate the direction the constraints take ('→' means downwards, and '←' means upwards the constraint hierarchy).

After some learning has taken place, i.e. after the learner encountered more forms like [t^ján.pa], TROCHAIC will swap places with IAMBIC, bringing perception and production into agreement, as shown in (134).

(134) An adjusted GLA-grammar

| t^jan.pa |	PARSE	AFL	AFR	FTBIN	TROCHAIC	IAMBIC
👄 👂 a. /(t^ján.pa)/						*
b. /(t^ján) pa/	*!		*			
c. /(t^ján)(pà)/		*!	*	*		
d. /t^jan (pá)/	*!	*		*		
e. /(t^jan.pá)/					*!	
f. /(t^jàn)(pá)/		*!	*	*		

In the simulations, the two learning strategies are compared with respect to their overall success in learning from the forms they are confronted with, but also with respect to their success in transferring what they have learned to forms they were not trained on.

5.4 Simulating the acquisition of Pintupi stress

The ingredients to the computer simulations are as before training data (5.4.1), a candidate generator (5.4.2), a set of constraints (the add-ons for Pintupi stress are given in 5.4.3), and the reranking strategies CD and GLA. The learners encountered the training data in a randomized order. The learners started out with an initial ranking where all constraints were ranked at the same heights (at 100.000). The CD learners had a plasticity of 1, meaning that constraints were reranked by 1 (e.g. first to 99 on the ranking scale, then to 98 etc.). They learned with zero evaluation noise and encountered 1 000 forms. The GLA learners had decreasing plasticity, starting out by 1, with four times a decrement of 0.1.[51] This means that in the

[51] 'Decreasing plasticity' means that the learners shifted constraints by 1.0 points on the ranking scale during the encounter of the first 10 000 data, by 0.1 points during encountering the second 10 000 data, by 0.01 points during encountering the third 10 000 data, and by 0.001 points the last 10 000 data, meaning that the learners took

beginning, the GLA learners took ranking steps as big as the CD learners (rather large ones), but decelerated their learning pace in the course of time. They were fed with 40 000 training forms.

5.4.1 The training data

The learning data set consists of 17 word-like forms, listed in (135). These forms are two to four syllables long and are made up of syllables and stress marks. Monosyllabic forms are excluded from the set since there is only one possibility to stress a monosyllabic word, therefore the virtual child cannot learn much about stress placement from it. The length of words is limited to at most four syllables for the following reasons: to account for the claim that child-directed speech are often simplified utterances (Phillips 1973) and to see what the learners will do when they are asked to produce forms that they have not been trained on. It was also noted by Hansen & Hansen (1969:162) that words consisting of two to four syllables are more frequent than monosyllabic words or words with more than four syllables. The learning set covers only a selection of all possible combinations of syllables in Pintupi.[52] All forms are overt, i.e. they contain stress marks, but neither foot nor moraic structure. Because I focus on the acquisition of stress here, the overt forms furthermore contained syllable boundaries.[53] The learners will know that each vowel in a syllable is inherently moraic, but they will not know that of coda consonants. GEN contains candidates with or without moraic coda consonants, and I expect the learners to decide for either one possibility or the other in response to the data they are trained on.

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smaller and smaller learning steps. This is to approach a realistic learning curve; in the beginning, learning takes place rather fast, while it slows down in the course of time.

[52] I chose only forms whose syllable structure matched the examples in the Hansen & Hansen (1969) paper for the learning data set.

[53] In fact, children also have to learn to set syllable boundaries as well as what kind of syllable structure their language allows, e.g. whether their language allows for codas and/or consonant clusters etc. This issue is beyond the scope of this dissertation and will have to be modelled elsewhere.

(135) The training data

2-syllable forms	3-syllable forms	4-syllable forms
[cv́.cv]	[cv́.cv.cv]	[cv́.cv.cv̀.cv]
[cv́.cvc]	[cv́.cv.cvc]	[cv́.cvc.cv̀.cv]
[cv́v.cv]	[cv́.cvc.cv]	[cv́.cvc.cv̀c.cvc]
[cv́c.cv]	[cv́c.cv.cv]	[cv́c.cv.cv̀.cv]
[cv́c.cvc]	[cv́c.cv.cvc]	[cv́c.cv.cv̀c.cv]
	[cv́c.cvc.cv]	[cv́c.cvc.cv̀c.cv]

5.4.2 The candidate generator

As we have seen in (135), the training data consist of overt forms with two, three, or four syllables. The syllables can have the shape of CV, CVV, or CVC; syllable boundaries, primary and secondary stress are given. This holds also for the candidates provided by GEN: the candidates are surface forms that consist of corresponding strings of CV-, CVV-, and CVC-syllables. Syllable boundaries are indicated. The candidates contain foot structures and stress marks for primary and secondary stress on various positions within the word. Feet may span over one or two syllables, but never over more than two syllables. In the case that there are coda consonants in a word, the candidate list will contain candidates with moraic representations, e.g. the candidate list for a word like |cvc.cvc| may contain candidates such as /(cv́c) cvc/, /(cv́c_{μ}.cvc_{μ})/, /(cv́c_{μ}.cvc)/, and the like.

5.4.3 The constraints

The constraints used for the simulations on Pintupi stress consist of the set in (14) of section 2.6.1 with some add-ons. To be able to model the learning data that contain syllable structure instead of syllables already labelled for light or heavy, *Cμ and WBP are added. To maintain an analysis with TROCHAIC, *CLASH and *LAPSE are added (*LAPSE as in Elenbaas & Kager 1999 is violated in forms that have more than two consecutive unstressed syllables, and is added as a counterpart to *CLASH). Once more I will test two different constraint sets, that only differ in their implementation of the trochaicity constraint:

(136) Constraint sets for the simulations

1) TROCHAIC learners	2) FTNONFINAL learners
AFL/AFR	AFL/AFR
FTBIN	FTBIN
TROCHAIC	FTNONFIN
IAMBIC	IAMBIC
MAIN-L/R	MAIN-L/R
NONFIN	NONFIN
PARSE	PARSE
WFL/WFR	WFL/WFR
WSP	WSP
*Cμ	*Cμ
WBP	WBP
*CLASH	*CLASH
*LAPSE	*LAPSE

The list for general metrical phenomena is complemented, but remains far from complete. My interest was to let the learners decide whether coda consonants are moraic or not; this constraint set enables them to do so. In the initial state all constraints are ranked equal.

This results in four different types of learners. Since each learner encounters the data in a different order, variation in the results is anticipated (as we have seen in chapter 4 on Latin stress). To check whether differences in the learning results will arise, 50 learners of each learning type were created, resulting in a total of 200 virtual learners:

(137) Learning types:

	TROCHAIC set	FTNONFIN set
CD learning strategy	50 learners	50 learners
GLA learning strategy	50 learners	50 learners

Apart from the rankings established in (117) and (120) it is expected that the constraints *LAPSE and WFL/WFR show little effect in the outcome, since an analysis of Pintupi stress is not depending on them. WSP should not show an effect because stress assignment should be weight-insensitive. *CLASH and FTBIN should only play a role in learners that have the TROCHAIC constraint set; as I have indicated above (section 5.2.2), FTNONFIN could in principle take over some of the functions of *CLASH and FTBIN. One can argue whether it should, though.

5.5 Results for Pintupi stress

The virtual learners with the CD strategy learned from tableaux as described in (126), (128), and (130), while the virtual learners with the GLA strategy learned from tableaux as described in (126), (128), and (133). The results were taken from the learners after their training on 1 000 (for the CD learners) and 40 000 forms (for the GLA learners) respectively. All 200 learners produced the same overt output, listed in table (138). Learning can be considered successful because primary stress is correctly on the first syllable in all forms and secondary stress is on the third syllable in forms with four syllables. The forms that occurred in the training data are printed in bold; all the other forms had to be created by the learners themselves.

(138) The overt output of all 200 virtual learners

disyllables	trisyllables	quadrisyllables	
[cv́.cv]	**[cv́.cv.cv]**	**[cv́.cv.cv̀.cv]**	[cv́v.cvc.cv̀.cv]
[cv́.cvc]	**[cv́.cv.cvc]**	[cv́.cv.cv̀.cvc]	[cv́v.cvc.cv̀.cvc]
[cv́v.cv]	**[cv́.cvc.cv]**	[cv́.cv.cv̀c.cv]	[cv́v.cvc.cv̀c.cv]
[cv́v.cvc]	[cv́.cvc.cvc]	[cv́.cv.cv̀c.cvc]	[cv́v.cvc.cv̀c.cvc]
[cv́c.cv]	[cv́v.cv.cv]	**[cv́.cvc.cv̀.cv]**	**[cv́c.cv.cv̀.cv]**
[cv́c.cv]	[cv́v.cv.cvc]	[cv́.cvc.cv̀.cvc]	[cv́c.cv.cv̀.cvc]
	[cv́v.cvc.cv]	[cv́.cvc.cv̀c.cv]	**[cv́c.cv.cv̀c.cv]**
	[cv́v.cvc.cvc]	**[cv́.cvc.cv̀c.cvc]**	[cv́c.cv.cv̀c.cvc]
	[cv́c.cv.cv]	[cv́v.cv.cv̀.cv]	[cv́c.cvc.cv̀.cv]
	[cv́c.cv.cvc]	[cv́v.cv.cv̀.cvc]	[cv́c.cvc.cv̀.cvc]
	[cv́c.cvc.cv]	[cv́v.cv.cv̀c.cv]	**[cv́c.cvc.cv̀c.cv]**
	[cv́c.cvc.cvc]	[cv́v.cv.cv̀c.cvc]	[cv́c.cvc.cv̀c.cvc]

However, the learners came up with five different ways of assigning foot structures that resulted in the correct overt stress pattern. An overview is given in table (139). The numbers in the last but one column refer to the number of learners that came up with the analysis at hand, the numbers in the last column give the percentages.

The 103 learners in table (139) came up with the foot structure proposed by linguists ("linguist's analysis"). Examples for this foot structure are /(cv́c.cv) cvc/ and /(cv́c.cv)(cv̀c.cv)/. The 5 GLA learners in (130b) analyzed coda consonants consistently as moraic, e.g. /(cv́c$_{\mu}$.cv) cvc$_{\mu}$/ and /(cv́c$_{\mu}$.cv)(cv̀c$_{\mu}$.cv)/. The 24 learners in (130c) analyzed only codas in stressed syllables as moraic, e.g. /(cv́c$_{\mu}$.cvc) cvc/ and /(cv́c$_{\mu}$.cvc)(cv̀c$_{\mu}$.cv)/. The 40 learners in (130d) analyzed final syllables consistently as being extrametrical, e.g. /(cv́c.cv) cvc/ and /(cv́c.cv)(cv̀c)cv/. Last but not least, 28 learners in (130e) analyzed codas as being moraic and final syllables as being extrametrical, e.g. as /(cv́c$_{\mu}$.cv) cvc$_{\mu}$/ and /(cv́c$_{\mu}$.cv)(cv̀c$_{\mu}$) cv/.

(139) Distribution of analyses

Analysis		GLA learners		CD learners		Total	%
		FtNonf	Troch.	FtNonf	Troch.		
a.	Linguist's analysis:	23	3	30	47	103	51.5
b.	Moraic codas:	5				5	2.5
c.	Moraic codas/ stressed syllables:	1		20	3	24	12
d.	Extrametricality:	11	29			40	20
e.	Extrametricality/ moraic codas:[54]	10	18			28	14

The different analyses are discussed in sections 5.5.1-5.5.5. The variation is not only due to evaluation noise in the GLA learners, as we can see from the different analyses of the CD learners. Each learner encountered the data in a different order, and I consider that to be the reason for the variation in the results

The virtual learners invented five different ways to realize the Pintupi overt stress pattern. The GLA/FtNonfin learners invented all five different ways. The learners with the GLA/Trochaic combination came up with three of these analyses, while the CD learners came up with two analyses.[55]

[54] One learner analysed final syllables as extrametrical and codas as moraic, but was not consistent in that within one form, some codas were moraic and some were not, independently of whether the codas occurred in stressed syllables. This learner is subsumed under category (130e).

[55] For the determination of the GLA learners' outputs the evaluation noise was set to zero, meaning that the ranking they displayed on check-up after learning was frozen in as the final ranking.

5.5.1 The linguist's analysis

Back in section 5.2 I established the foot structure linguists would assign to the Pintupi stress pattern: disyllabic, left-headed feet assigned iteratively from left to right, unfooted final syllables in odd-numbered words, and coda consonants as not moraic. 103 learners came up with this pattern, as shown in (140):

(140) Examples for the foot structure in the linguist's analysis

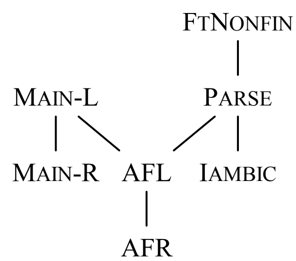
overt forms	surface forms
[cv́.cvc]	/(cv́.cvc)/
[cv́v.cv]	/(cv́v.cv)/
[cv́c.cv.cvc]	/(cv́c.cv) cvc/
[cv́v.cv.cv̀.cvc]	/(cv́v.cv)(cv̀.cvc)/

The grammars that the learners came up with to produce this pattern are discussed next. Section 5.5.1.1 discusses the FTNONFIN learners, and section 5.5.1.2 discusses the TROCHAIC learners.

5.5.1.1 FTNONFIN learners

23 GLA/FTNONFIN learners and 30 CD/FTNONFIN learners came up with a constraint ranking that assigned feet in the way described above. In order to be able to compare the rankings of the learners with that established in section 5.2, the ranking in figure (117) is repeated here as figure (141):

(141) A crucial ranking for an analysis of FTNONFIN learners



GLA/FtNonfin learners. A final constraint ranking typical for a GLA/FtNonfin learner is shown in (142). For once, I show the complete hierarchy with ranking values, and will for the remainder of the chapter restrict myself to crucial differences in the learners' constraint rankings. Important is whether the crucial rankings are maintained: Main-L outranks Main-R and AFL; FtNonfin outranks Parse and Iambic. Parse in turn outranks Iambic and AFL, and AFL dominates AFR. *Cμ is ranked above WBP, therefore coda consonants do not surface as moraic.

(142) The ranking of a GLA/FtNonfin learner

FtNonfin	116.116
*Lapse	111.136
Main-L	110.243
WFL	108.154
FtBin	106.977
Parse	105.028
*Cμ	104.139
*Clash	104.089
Nonfin	101.947
AFL	101.028
WSP	100.915
WFR	98.053
WBP	95.861
AFR	95.017
Main-R	93.846
Iambic	81.759

We can evaluate this ranking with e.g. *ŋalkuninpa*. In tableau (143), the first three candidates contain a single foot and are ruled out. The two candidates that do not align this foot with the left word edge are ruled out because they violate high-ranking Main-L. The very first candidate is ruled out by lower-ranked Parse, because it has two unfooted syllables. Candidate (134e) is ruled out by top-ranked FtNonfin, because it contains a monosyllabic foot. Candidate (134f) is ruled out by Main-L; it has two proper trochaic feet, but the head foot is not aligned with the left word edge. That leaves candidate (134d) as the winner: it has two proper trochaic feet, and the head-foot is aligned with the left word edge. Neither does it violate any of the other high-ranking constraints which I left out of the tableau to focus on the ranking proposed in figure (141). For clarity's sake, I will only include the relevant constraints in the upcoming tableaux. For instance, the weight constraints are left out until effects of weight show up in the learners data.

(143) A GLA learner producing /(ŋál.ku)(nìn.pa)/

∣ ŋal.ku.nin.pa ∣	FTNONFIN	MAIN-L	PARSE	AFL	AFR	MAIN-R	IAMBIC
a. /(ŋál.ku) nin.pa/			*!*		**	**	*
b. /ŋal.ku (nín.pa)/		*!*	**	**			*
c. /ŋal (kú.nin) pa/		*!	**	*	*	*	*
☞ d. /(ŋál.ku)(nìn.pa)/				**	**	**	**
e. /(ŋál.ku)(nìn) pa/	*!		*	**	***	**	*
f. /(ŋàl.ku)(nín.pa)/		*!*		**	**		**

In sum it can be said that the losing candidates were filtered out by the constraints which *should* have filtered them out, according to the crucial constraint ranking given in figure (117) (or in figure (141), respectively).

Next, I will discuss a case of a CD learner who came up with the same foot structure, yet a different ranking.

CD/FTNONFIN learners. A constraint ranking typical for the CD/FTNONFIN learners that came with said foot structure is shown in figure (144):

(144) The ranking of a CD/ FTNONFIN learner

*CLASH, *LAPSE, AFR, FTBIN, FTNONFIN, MAIN-L, WFL, WSP
>>
*Cμ, AFL, IAMBIC, MAIN-R, NONFINAL, PARSE, WFR
>>
WBP

We can see that the crucial ranking of MAIN-L over MAIN-R and AFL is accomplished, as well as the ranking of FTNONFIN above IAMBIC and PARSE. However, PARSE is ranked on the same stratum as AFL and IAMBIC, and AFR even outranks PARSE and AFL. Other learners that came up with this foot structure had the three constraints ranked on the same stratum. How come that the desired foot structure still shows? If we only pick out the constraints that we defined as being responsible for the foot structure described above, we do not end up with the desired candidate: in tableau (145), the desired candidate (marked with a '☹') is ruled out because it has more violations in the lower stratum than the competing candidates (136a), (136b) and (136c). The candidates (136e) and (136f) are ruled out because they have more violations than the others in the first stratum.

(145) A CD learner producing *ŋalkuninpa*

| ŋal.ku.nin.pa |	AFR	FTNONFIN	MAIN-L	AFL	IAMBIC	PARSE	MAIN-R
☞ a. / (ŋál.ku) nin.pa /	**				*	**	**
☞ b. / ŋal.ku (nín.pa) /			**	**	*	**	
☞ c. / ŋal (kú.nin) pa /	*		*	*	*	**	*
☹ d. / (ŋál.ku)(nìn.pa) /	**			**	**		**!
e. / (ŋál.ku)(nìn) pa /	***!	*		**	*	*	**
f. / (ŋàl.ku)(nín.pa) /	**(!)		**(!)	**	**		

It is the notion of crucial ties (e.g. Tesar & Smolensky 2000:38) which enables the CD learners to come up with the Pintupi stress pattern although the constraints are not totally ranked. If we take into account all constraints that were implemented in the learning process and that remained high-ranking, we get the correct candidate, as shown in tableau (146). The reason why /(ŋál.ku)(nìnpa)/ surfaces instead of e.g. */(ŋál.ku) nin.pa/, although AFR outranks PARSE *and* AFL, is that /(ŋál.ku)(nìnpa)/ violates only AFR of all the constraints in that stratum (two violations in total), while */(ŋál.ku) nin.pa/ violates AFR and *LAPSE (three violations in total), */ŋal.ku (nín.pa)/ violates MAIN-L and WFL (also three violations), and */ŋal (kú.nin) pa/ violates AFR, MAIN-L and WFL. These CD learners apparently did not find evidence in the data to demote AFR below AFL.

(146) A decision based on crucial ties

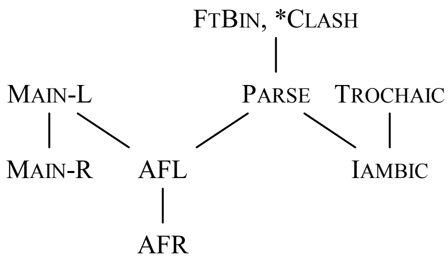
| ŋal.ku.nin.pa |	*LAPSE	AFR	FTBIN	FTNONFIN	MAIN-L	WFL	AFL	IAMBIC	MAIN-R	PARSE
a. /(ŋál.ku) nin.pa/	*(!)	**(!)						*	**	**
b. /ŋal.ku (nín.pa)/					**(!)	*(!)	**	*		**
c. /ŋal (kú.nin) pa/		*(!)			*(!)	*(!)	*	*	*	**
☞ d. /(ŋál.ku)(nìn.pa)/		**					**	**	**	

In sum, although AFR paradoxically outranks AFL, the wished-for foot structure could still surface thanks to the other constraints ranked on that stratum.

5.5.1.2 TROCHAIC learners

Three GLA/TROCHAIC learners and 47 CD/TROCHAIC learners came up with the linguist's analysis. The ranking of figure (120) is for convenience repeated as figure (147):

(147) A crucial ranking with TROCHAIC



First I discuss the GLA learners and then the CD learners.

GLA/TROCHAIC learners. In the grammar of a GLA learner shown in tableau (148), MAIN-L properly outranks MAIN-R and AFL. TROCHAIC outranks IAMBIC, while FTBIN and *CLASH outrank PARSE. PARSE in turn dominates AFL that dominates AFR. The numbers above the columns indicate the actual ranking values of the constraints in the end-grammar. None of the shown candidates violates TROCHAIC. MAIN-L rules out candidate (139b) with a right-aligned foot. FTBIN rules out candidate (139d), which has a monosyllabic foot in final position. *CLASH rules out candidate (139c), which has a binary (since bimoraic) foot. This leaves candidate (139a) as the winner: /(mí:l^j.ma) nu/ has a left-aligned, disyllabic foot.

(148) A GLA/Trochaic learner producing *mil^{j}manu*

	117.881	117.027	116.740	112.413	107.834	94.073	92.415	90.349	57.590
|mi:l^j.ma.nu|	TROCHAIC	MAIN-L	FTBIN	*CLASH	PARSE	MAIN-R	AFL	AFR	IAMBIC
☞ a. /(mí:l^j.ma) nu/					*	*		*	*
b. /mi:l^j (má.nu)/		*!			*		*		*
c. /(mí:l^j)(mà.nu)/				*!		**	*	**	*
d. /(mí:l^j.ma)(nú)/			*!			*	**	*	*

CD/TROCHAIC learners. In the CD/TROCHAIC learners, e.g. the showcase in tableau (149), the crucial rankings are not all borne out. MAIN-L is ranked above MAIN-R, *Cμ is ranked above WBP, and TROCHAIC is ranked above IAMBIC; but FTBIN, *CLASH, PARSE, AFL and AFR are ranked on the same stratum. Again, the exclusion of the competing candidates is taken care of by the crucial ties on the first stratum.

(149) An CD /TROCHAIC learner producing *mil^{j}manu*

|mi:l^j.ma.nu|	TROCHAIC	MAIN-L	FTBIN	*CLASH	PARSE	AFL	AFR	MAIN-R	IAMBIC
☞ e. /(mí:l^j.ma) nu/					*		*	*	*
f. /mi:l^j (má.nu)/		*(!)			*(!)	*(!)			*
g. /(mí:l^j)(mà.nu)/				*(!)		*(!)	**(!)	**	*
h. /(mí:l^j.ma)(nú)/			*(!)			**(!)	*(!)	*	*

5.5.1.3 Summary

The ranking of FTBIN over PARSE is not always maintained: some learners had these constraints reversed (some GLA/FTNONFIN learners), or ranked on the same stratum (some CD/TROCHAIC learners). High-ranking FTNONFIN will ensure that trochaic feet are disyllabic, and prohibit degenerate feet such as (cv́). In this way FTNONFIN takes over the function of FTBIN and even *CLASH, so the ranking between PARSE and FTBIN becomes irrelevant. This also explains why FTBIN and PARSE are often very close to each other in terms of ranking values across learners of all conditions. In the CD learners, it is due to the crucial ties that the required forms still surface.

So much for the learners that created foot structure like the one proposed by e.g. Hayes (1995) or Kager (1999) for Pintupi stress. In the next section, I discuss the analyses of the learners that interpreted coda consonants as moraic. Remember that their overt forms nevertheless show the Pintupi stress pattern.

5.5.2 Moraic coda consonants

Five of the 50 GLA/FTNONFIN learners analyzed coda consonants as being moraic in the surface form (regardless whether they occur in stressed syllables or not). None of the other types of learners came up with this analysis. The foot structure that these learners assign is the same as for the linguist's analysis, but coda consonants are consistently analyzed as being heavy, marked with a subscript 'μ' as illustrated in (150). Stress assignment in these forms is clearly weight-insensitive.

(150) Coda consonants analyzed as moraic

overt forms	surface forms
[cv́.cvc]	/(cv́.cvc_{μ})/
[cv́c.cvc.cv]	/(cv́c_{μ}.cvc_{μ}) cv/
[cv́.cvc.cv̀c.cv]	/(cv́.cvc_{μ})(cv̀c_{μ}.cv)/

The ranking of WBP over *Cμ and WSP is responsible for the moraic analysis of these learners. The ranking of these constraints with respect to the others is shown in figure (151).

(151) A crucial ranking for moraic codas

```
WBP              FTNONFIN, MAIN-L
 |    \          /
*Cμ     WSP
```

Tableau (152) demonstrates how a GLA/FTNONFIN learner with such a ranking would produce a word like *ŋalkuninpa*. I only include four constraints and three candidates for the sake of clarity: FTNONFIN filters out the last candidate */(ŋál$_{\mu}$)(kú.nin$_{\mu}$) pa/ because of its bimoraic foot on the first syllable. WBP filters out the candidate which surfaced as optimal in the tableaux (143) and (146). The candidate that has the same foot structure, but moraic coda consonants, surfaces as optimal. The numbers above the constraint columns are the actual ranking values of this learner and indicate the distances between the constraints.

(152) A GLA/FTNONFIN learner producing *ŋalkuninpa*

		115.277	102.396	97.604	96.065
	|ŋal.ku.nin.pa|	FTNONFIN	WBP	*Cμ	WSP
	/(ŋál.ku)(nìn.pa)/		*!*		
☞	/(ŋál$_{\mu}$.ku)(nìn$_{\mu}$.pa)/			**	
	/(ŋál$_{\mu}$)(kú.nin$_{\mu}$) pa/	*!		**	*

In contrast to the learners with the linguist's analysis, these learners ranked WBP above *Cμ. Remember that WBP requires coda consonants to be moraic, while *Cμ militates against moraic codas. WSP, the constraint favouring stressed heavy syllables, is crucially ranked below the constraints FTNONFIN and MAIN-L. A reverse ranking would bring about stress sensitivity to heavy syllables (i.e. syllables with coda consonants). These learners analyzed coda consonants as being always moraic, even in unstressed position. This is shown in tableau (153). The first candidate */(já.lin)(t^{j}à.ra)/ is ruled out by WBP. The second candidate /(já.lin$_{\mu}$)(t^{j}à.ra)/ wins because of its moraic coda.

(153) *jalint^{j}ara* 'north'

∣ ja.lin.t^{j}a.ra ∣	WBP	*Cμ	WSP
/ (já.lin)(t^{j}à.ra) /	*!		
☞ / (já.lin$_μ$)(t^{j}à.ra) /		*	*

The learners of this analysis assign stress clearly weight-insensitively, since the syllables with moraic codas do not attract stress. In the following section the learners are presented that analyzed codas only as moraic when they occur in a stressed position.

5.5.3 Moraic coda consonants in stressed syllables only

One GLA/FTNONFIN learner, 20 CD/FTNONFIN learners and 3 CD/TROCHAIC learners analyzed codas only in stressed syllables as moraic, as illustrated in table (154). Foot structure was perfectly disyllabic and trochaic, assigned from left to right, just like in the linguist's analysis.

(154) Moraic codas in stressed syllables

overt forms	surface forms
[cv́c.cvc]	/(cv́c$_μ$.cvc)/
[cv́c.cv.cvc]	/(cv́c$_μ$.cv) cvc/
[cv́v.cvc.cv̀c.cv]	/(cv́v.cvc)(cv̀c$_μ$.cv)/

These learners drew the conclusion that only codas in stressed positions are heavy. This effect smells like the 'stress-to-weight' principle (Myers 1987; Prince 1990), and has its cause in the ranking of WSP above WBP, which has to be ranked above *Cμ in turn, as argued in §5.2.3. The other constraints are ranked as in the other analyses:

(155) The crucial ranking for moraic codas in stressed syllables

WSP >> WBP >> *Cμ

We have already observed that only if WBP is ranked above *Cμ, coda consonants can be moraic. If WSP now outranks WBP and *Cμ, only coda consonants that occur in a stressed syllable are moraic, because WSP would cause codas in unstressed syllables not to be moraic.

Taking a GLA learners as a basis for the evaluation in tableau (156), we can see that a candidate where all codas are moraic is ruled out by WSP, while the candidate without moraic codas is ruled out by the second violation of WBP. The candidate with a moraic coda in stressed position violates WBP only once, and surfaces as optimal:

(156)*puɭiŋkalpi* ‘(he fell) finally at the hill’

	115.849	110.192	102.254	100.892	99.108
| pu.ɭiŋ.kal.pi |	FtNonf	Main-L	WSP	WBP	*Cμ
/(pú.ɭiŋμ)(kàlμ.pi)/			*!		**
☞ /(pú.ɭiŋ)(kàlμ.pi)/				*	*
/(pú.ɭiŋ)(kàl.pi)/				**!	

The CD learners show the same ranking of WSP >> WBP >> *Cμ.

5.5.4 Final syllable extrametricality

As established in section 5.2.1, final syllables in Pintupi are unfooted if the word has an odd number of syllables, because a monosyllable is too small to be parsed into a foot. This results in some forms with syllable extrametricality “by accident”, as it were, as in /(cv́v.cv) <cv>/. It might not be straightforward to analyze forms like that as being the result of the involvement of a constraint like Nonfinal. However, learners of the language could misinterpret those forms as an occurrence of extrametricality caused by Nonfinal. And indeed, eleven of the 50 GLA/FtNonfin and 29 of the GLA/Trochaic learners analyzed *all* final syllables as being extrametrical, even at the cost of having degenerate feet, as in table (157).

(157) All final syllables extrametrical

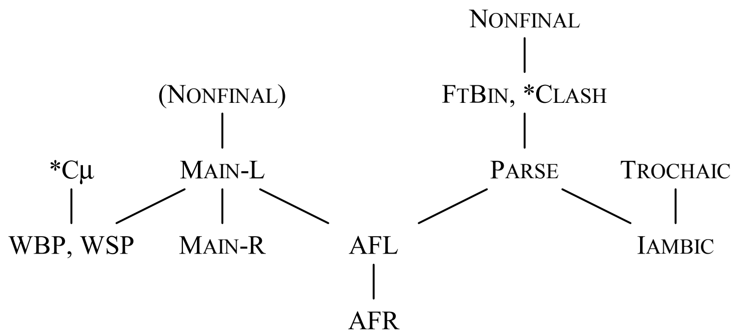
	overt forms	surface structures
a.	[cv́.cv]	/(cv́) cv/
b.	[cv́v.cv.cvc]	/(cv́v.cv) cvc/
c.	[cv́v.cv.cv̀.cvc]	/(cv́v.cv)(cv̀) cvc/

This is not surprising if one considers the Pintupi data and bears in mind that learners have the constraint NONFINAL to their disposal: the learners might interpret forms as having syllable extrametricality, because all words have unstressed final syllables. So some of the learners ended up with a ranking that put NONFINAL above FTNONFIN/TROCHAIC:

(158) A crucial ranking for final syllable extrametricality
NONFINAL >> { FTNONFIN, PARSE, FTBIN }

The ranking of MAIN-L >> MAIN-R, FTNONFIN >> IAMBIC, and PARSE >> AFL >> AFR is nevertheless borne out. *Cμ outranks WBP, so that coda consonants are not moraic.

(159) A crucial ranking for extrametricality with TROCHAIC



The effect of this ranking is exemplified in tableau (160). The candidate with disyllabic feet is ruled out by top-ranking NONFINAL, rendering the candidate with an extrametrical syllable as the winner:

(160) *ŋalkuninpa* 'eating'

	117.690	107.054	101.627	90.762
| ŋal.ku.nin.pa |	NONFINAL	PARSE	FTNONF	FTBIN
/ (ŋál.ku)(nìn.pa) /	*!			
☞ / (ŋál.ku)(nìn) pa /		*	*	*

None of the CD learners came up with an analysis like this. The answer is probably again to be found in the fact that CD learners learn with crucial ties. Candidates that satisfy NONFINAL are probably harmonically bounded, most of the time, and ruled out by the violations of the other constraints on that stratum, in the interpretive parse, seen in tableau (161), as well as in production, seen in tableau (162). FTBIN is violated in the candidates with monosyllabic feet, because codas are analyzed as not being moraic by these learners (candidates with moraic codas are left out).

(161) A CD learner interpreting *ŋalkuninpa*

[ŋál.ku.nìn.pa]	NONFINAL	PARSE	FTNONF	FTBIN
☞ /(ŋál.ku)(nìn.pa)/	*			
/(ŋál.ku)(nìn) pa/		*(!)	*(!)	*(!)

(162) A CD learner producing *ŋalkuninpa*

|ŋal.ku.nin.pa|	NONFINAL	PARSE	FTNONF	FTBIN
☞ /(ŋál.ku)(nìn.pa)/	*			
/(ŋál.ku)(nìn) pa/		*(!)	*(!)	*(!)
/(ŋál.ku) nin.pa/		**!		

A number of GLA learners combined the extrametricality and moraic coda analyses. This is shown in the next section. Since there are no CD learners that found the extrametricality analysis, no CD learners have found the combined analysis of extrametrical syllables and moraic codas.

5.5.5 Moraic codas and final syllable extrametricality

10 of the 50 GLA/FTNONFINAL learners analyzed coda consonants as being moraic and final syllables as extrametrical. This results in degenerate feet even in words with an even number of syllables:

(163) Moraic codas and syllable extrametricality

overt forms	surface forms
[cv́v.cvc]	/(cv́v) cvc$_{\mu}$/
[cv́c.cv]	/(cv́c$_{\mu}$) cv/
[cv́c.cvc.cvc]	/(cv́c$_{\mu}$.cvc$_{\mu}$) cvc$_{\mu}$/
[cv́.cvc.cv̀.cvc]	/(cv́.cvc$_{\mu}$)(cv̀) cvc$_{\mu}$/

Final syllable extrametricality is due to the ranking of NONFINAL above FTNONFIN, FTBIN, and PARSE. Moraic codas come along with the ranking of WBP above *Cµ and WSP.

While none of the GLA/TROCHAIC learners came up with an analysis of moraic codas, quite a number of them (17 learners) came up with an analysis that had both moraic codas and extrametrical syllables. As shown in tableau (164), NONFINAL is ruling out all candidates that have the final syllable footed. The decision between the candidates with extrametrical syllables is made by WBP, leaving the candidate with moraic codas as the optimal output.

(164) *puɭiŋkalpi* '(he fell) finally at the hill'

	114.347	105.539	103.617	101.062	98.938	96.217	94.256
| pu.ɭiŋ.kal.pi |	NONFIN	TROCHAIC	PARSE	WBP	*Cµ	FTBIN	WSP
/(pú.ɭiŋ$_{\mu}$)(kàl$_{\mu}$.pi)/	*!				**		*
/(pú.ɭiŋ)(kàl$_{\mu}$.pi)/	*!			*	*		
/(pú.ɭiŋ)(kàl.pi)/	*!			**			
☞ /(pú.ɭiŋ$_{\mu}$)(kàl$_{\mu}$) pi/			*		**		*
/(pú.ɭiŋ)(kàl$_{\mu}$) pi/			*	*!	*		
/(pú.ɭiŋ)(kàl) pi/			*	*!*		*	

The GLA/FTNONFINAL learners showed a similar ranking; if we replaced TROCHAIC with FTNONFIN in the tableau above, it would still render the same candidate as optimal.

5.5.6 Summary

To sum up shortly, all 200 virtual learners created grammars that describe the data they heard during the training phase. Nevertheless they created different grammars which is reflected in different surface structures. This does no harm, since all these surface structures translate to uniform overt outputs. Communication between these learners is guaranteed, because when talking to each other they wouldn't realize that their grammars differ. Let us now have a look at what the learners do when they have to abstract away from the familiar forms, and have to determine the stress pattern of words they have not been trained on.

5.6 Generalizations to unheard forms

In line with the tradition in computational linguistics (e.g. Manning & Schütze 1999:577) the virtual learners were asked to make generalizations, i.e. predict the stress pattern of words they were not trained on. This provides evidence for to what extent the learners are able to abstract away from the type of forms they heard in the training phase to a grammar accounting for the language. As outlined in 5.4.1, the learners have been trained on a set of 17 types of di- to quadrisyllabic words. After the training phase, the virtual learners were tested on what stress and foot structure they assign to forms they had not heard before. Among them were all di- to quadrisyllabic combinations of CV-, CVC- and CVV-syllables that are allowed in Pintupi, as listed in (138). The learners were then tested what stress and foot structure they assign to forms that contain long vowels in any syllable within the word, like [cv́.cvv.cvc] or [cv́.cv.cvv] (discussed in 5.6.1). Furthermore they were tested on what stress they assign to forms with more than four syllables (discussed in 5.6.2). The five-syllable forms consist of all possible combinations of syllable forms (forms like *puḻiŋkalatʲu*, but also non-attested forms of Pintupi with long vowels in non-initial position), and the six- and seven-syllable forms consist of CV-strings. 86 learners transferred the stress pattern they have been trained on to forms with more than four syllables and to forms with long vowels in other syllables than the initial one (these forms are actually not attested in Pintupi, but one could imagine a real-life scenario where speakers of Pintupi are confronted with loanwords with that kind of syllable structure). All of them were GLA learners. The CD learners mostly generalized to weight-sensitive forms. An overview of the results is given in (165):

(165) Summary of generalizations

Generalizations	GLA learners		CD learners		Total
	FTNONF	TROCHAIC	FTNONF	TROCHAIC	%
a. Linguist's analysis:	14	0	0	0	7.0 %
b. Moraic codas:	5	0	0	0	2.5 %
c. Moraic codas /stressed syllables only:	0	1	0	0	0.5 %
d. Extrametricality	10	29	0	0	19.5 %
e. Extrametricality/moraic codas:	10	17	0	0	13.5 %
					= 43%

In total, 43% of all 200 learners came up with a Pintupi-like pattern; all of them GLA learners. Of the 50 GLA/FTNONFIN learners, 78% (19.5% of all 200 learners) came up with a Pintupi-like pattern. Of the 50 GLA/TROCHAIC learners, 94% (23.5% of all 200 learners) came up with a Pintupi-like pattern.

5.6.1 Generalizations to unattested forms

Some examples are given in (166) for generalizations to forms with non-initial long vowels that the GLA learners produced:

(166) Generalizations to forms with non-initial long vowels

overt forms	surface structures
[cv́.cvv]	/(cv́.cvv)/ or /(cv́) cvv/
[cv́c.cvv]	/(cv́c.cvv)/ or /(cv́c) cvv/
[cv́.cv.cvv]	/(cv́.cv) cvv/
[cv́.cvv.cvc]	/(cv́.cvv) cvc/
[cv́.cvc.cvv]	/(cv́.cvc) cvv/
[cv́v.cv.cvv]	/(cv́v.cv) cvv/
[cv́.cvv.cv̀.cvc]	/(cv́.cvv)(cv̀.cvc)/ or /(cv́.cvv)(cv̀) cvc/
[cv́.cvc. cv̀.cvv]	/(cv́.cvc)(cv̀.cvv)/ or /(cv́.cvc)(cv̀) cvv/

The overt forms that these learners produced had primary stress on the initial syllable, and secondary stress on every other following syllable (except when that syllable was final in the word). It would be interesting to see whether real Pintupi-speakers would stress loanwords that contain long vowels in non-initial position like that.

The constraint ranking responsible for the weight-insensitive treatment of forms with non-initial long vowels is MAIN-L and FTNONFIN above WSP in the group of FTNONFIN learners and MAIN-L and *CLASH above WSP in the group of the TROCHAIC learners. MAIN-L >> WSP guarantees that the foot with main stress will be aligned to the left edge of the word, so that a heavy syllable cannot attract stress away from the edge. FTNONFIN >> WSP prevents stress clashes. In the TROCHAIC group, *CLASH takes care of that.

Consider a learner of the GLA/FTNONFIN-group that was able to generalize to this weight-insensitive pattern. In tableau (167) we can see for the first time an effect of WFL, ruling out a candidate */cv (cv́v.cv) cvc/ with stress on the heavy syllable. Even without this constraint, the same candidate would be ruled out by PARSE. The optimal candidate is (158a), /(cv́.cvv)(cv̀.cvc)/, which has not a moraic coda. Its direct competitor, */(cv́.cvv)(cv̀) cvc/, is ruled out by *Cμ, which is ranked above WBP.

(167) Generalization to unattested forms

| cv.cvv.cv.cvc |	FTNONFIN	MAIN-L	FTBIN	WFL	PARSE	*Cμ	WSP	WBP
☞ a. /(cv́.cvv)(cv̀.cvc)/							*	*
b. /(cv́.cvv)(cv̀) cvc/	*!		*		*		*	*
c. /(cv́.cvv)(cv̀.cvc_{μ})/						*!	**	
e. /cv (cv́v)(cv̀.cvc)/	*!			*	*			*
g. /cv (cv́v.cv) cvc/				*!	**			*
h. /cv (cv́v)(cv̀.cvc_{μ})/	*!			*	*	*	*	

5.6.2 Generalizations to longer forms

The learners were also tested what stress pattern they would assign when asked to produce words with more than four syllables. Some examples for

Pintupi-like generalizations to forms with five to seven syllables are given in (168):

(168) Generalizations to five-syllable forms and longer

overt forms	surface forms
[cv́.cvv.cv̀v.cv.cvc]	/(cv́.cvv)(cv̀v.cv) cvc/
[cv́.cvv.cv̀.cvv.cvc]	/(cv́.cvv)(cv̀.cvv) cvc/
[cv́c.cvv.cv̀v.cvc.cvv]	/(cv́c.cvv)(cv̀v.cvc) cvv/
[cv́.cv.cv̀.cv.cv̀.cv]	/(cv́.cv)(cv̀.cv)(cv̀.cv)/ or /(cv́.cv)(cv̀.cv)(cv̀) cv/
[cv́.cv.cv̀.cv.cv̀.cv.cv]	/(cv́.cv)(cv̀.cv)(cv̀.cv) cv/

Consider the grammar of a GLA/TROCHAIC learner with such a pattern. The form with six syllables has an extrametrical syllable due to high-ranking NONFINAL, but stress is nonetheless Pintupi-like: the first syllable has primary stress, the third and fifth syllables have secondary stress. MAIN-L makes sure that stress is aligned with the left word edge, while PARSE makes sure that there are three feet in the word (the numbers in the cells indicate the number of constraint violation):

(169) Generalization to forms with six syllables

| cv.cv.cv.cv.cv.cv |	NONFIN	MAIN-L	*LAPSE	TROCHAIC	WFL	PARSE	FTBIN	AFL	AFR
☞ a. /(cv́.cv)(cv̀.cv)(cv̀) cv/						*	*	6	7
b. /(cv́.cv)(cv̀.cv)(cv̀.cv)/	*!							6	6
c. /cv (cv́.cv)(cv̀.cv) cv/		*!			*	**		4	4
d. /(cv́.cv) cv (cv̀.cv) cv/						**!		3	5
e. /(cv́.cv) cv.cv (cv̀.cv)/	*!		*			**		4	4

It can be concluded that most of the GLA learners found enough evidence in the data to rank AFL above AFR, resulting in a left-to-right directionality of foot assignment. The implication of this finding would be that when learning from words with up to four syllables, the language learners are able to generalize to a Pintupi-like pattern in words with five and more syllables, but not to a Garawa-like pattern.

5.6.3 Generalizations to other stress patterns

Of the 200 learners, 57% generalized to patterns quite different from the weight-insensitive, left-aligned pattern proposed for Pintupi. Among them were all CD learners. Many of them displayed a strong tendency for weight-sensitivity in forms with long vowels in non-initial position and produced forms like /(cv.cv́v) cv (cv̀v.cvv)/. From the data they were trained on they did not infer the ranking of MAIN-L, *CLASH and FTNONFIN above WSP, that would be crucial for a weight-insensitive analysis. Once again, the reason are the crucial ties. One could say that CD learners would show a different stress pattern for loanwords than most of the GLA learners. Which one is the correct pattern attested by real Pintupi speakers is yet to be shown.

Another difference was the alignment of feet. Many of the longer forms contained feet that were not properly stringed together, but left out syllables. This comes about with the equal ranking of AFL and AFR. AFL would have to outrank AFR in order to properly align the feet. Learners with an equal ranking of the two constraints therefore produced forms like /(cv́.cv) cv (cv̀.cv).cv/ and even forms with iambic feet for the form as /(cv.cv́) cv.cv.cv.cv.cv/, with seven syllables. The iamb could occur because the constraints in the first stratum could not evaluate an optimal candidate, and the decision was left to the lower ranked IAMBIC constraint. However, only one single CD learner came up with a Garawa-like pattern (where primary stress is assigned to the initial syllable, but secondary stress is iteratively assigned from the right). Most of the other CD learners showed a strong tendency to weight-sensitivity. This could mean that there is a learning path to Pintupi stress when learning from two- to four syllable forms, but not to Garawa.[56]

A general reason for this deviation could be that any of the ingredients in this modelling of stress is deficient. The constraints might be poor descriptions of their function, the learning algorithms could be wrong, the training set could have been too impoverished or OT as a theory of learning

[56] It is likely that it was only accidental that one learner out of 200 found the Garawa pattern.

could be inadequate. That all of the learners came up with an overt stress pattern that is Pintupi-like suggests that the ingredients are quite sufficient, though.

5.7 The control group: learning from polysyllabic forms

One point of discussion is whether the learners would be able to create a more uniform foot structure when trained on a more complete set of data. I therefore tested the four types of learners (10 GLA/FTNONFIN learners, 10 GLA/TROCHAIC learners, 10 CD/FTNONFIN learners, 10 CD/TROCHAIC learners) on a bigger training set consisting of two- to five-syllable forms with all combinations of syllable structures that are licit in Pintupi, plus six- and seven-syllable forms consisting of CV-syllables only. The results are summed up in table (170). Almost all CD learners (47,5% of all the 40 learners of the control group) came up with left-aligned, disyllabic feet as in (161a), while only 5% of the GLA learners chose this analysis. Most of the GLA learners (35% of all the 40 learners of the control group) chose to analyze all final syllables as extrametrical, as in (161d). Some GLA learners (10%) chose to analyze the Pintupi pattern as having final syllables extrametrical and codas as moraic (161e). One CD learner (2.5%) chose to analyze codas in stressed syllables as being moraic (161c). No learner of the control group analyzed the Pintupi pattern as having left-aligned, disyllabic feet with moraic codas (161b).

(170) Resulting foot structures when learning from complete data

Analysis		GLA learners		CD learners		Total	%
		FTNONF	TROCH.	FTNONF	TROCH.		
a.	Linguist's analysis:	1	1	9	10	21	52.5
b.	Moraic codas:						
c.	Moraic codas/ stressed syllables:			1		1	2.5
d.	Extrametricality:	7	7			14	35.0
e.	Extrametricality/ moraic codas:	2	2			4	10.0

The results roughly correspond to the analyses of the tested group in (139): the majority of the test group chose for the left-aligned, disyllabic pattern (51.5% vs. 52.5% in the control group), while the next biggest group chose for the extrametrical analysis (20% vs. 35% in the control group). A smaller percentage of the test group chose for the combined extrametrical/moraic-coda analysis (14% vs. 10% in the control group). An even smaller percentage chose for the moraic-codas-in-stressed-syllables-only analysis (12% vs. 2.5% in the control group). In the test group, 2.5% learners came up with the moraic-codas-everywhere analysis, while none of the learners in the control group came up with this analysis. This gap is probably accidental; if I ran a bigger control group, some learners might pop up analyzing codas as being always moraic. As for the distinction between GLA and CD learners, we also find a rough correspondence to the distribution in (139). None of the CD learners in the test group came up with the moraic-coda analysis, or with the extrametrical analysis, or with the combined extrametrical/moraic-coda analysis, and none of the CD learners of the control group came up with any of those analyses. Therefore I conclude that the imperfect training data shown in (135) for the test group were sufficient information to deduce a Pintupi adult-like grammar from.

5.8 Discussion

In the simulations of this chapter, all learners acquired the stress pattern in the sense that they produced stress on the correct syllable within a word, i.e. their overt production was the same as the overt forms in the target language. Despite the fact that the overt forms were the same, the learners came up with different analyses, though. More than half of the learners (all in all 103) came up with an analysis similar to the one linguists have come up with for Pintupi stress (e.g. Hayes 1995, Kager 1999). Five learners analysed coda consonants as moraic, but apart from that assigned the same foot structure as a linguist would assign it. Twenty-four learners treated only stressed codas as moraic, nonetheless assigning disyllabic feet from left to right. These three groups of learners can be clustered together as one group in terms of foot structure, resulting in a total of 132 learners that came up not only with the desired stress pattern but also with the desired foot structure. The remaining learners assigned a different foot structure in that they always left final syllables unfooted. Some of them assigned this foot structure in combination with moraic codas. Stress assignment was nevertheless Pintupi-like and weight-insensitive.

There are several reasons why different analyses were possible. One is the fact that the learners encountered the same data, but in a different order. Depending on which forms you encounter a lot in the beginning, your perception changes to the extent your grammar changes. This applies even more for the GLA learners, since they learned with a plasticity decrement, i.e. they took bigger learning steps in the beginning and were slowing down over time.

Moreover, the data that the learners encountered do not give explicit evidence as to whether codas in Pintupi are moraic or not, so some learners interpreted codas as being moraic (WBP >> *Cμ), while others did not (*Cμ >> WBP). Evidence for/against syllable extrametricality in Pintupi is not unambiguous, either. The data in Pintupi do not show explicit evidence for or against the footing of final syllables. Syllable extrametricality comes about with a ranking of NONFINAL above FTNONFIN and FTBIN.

A further reason for the variation in analyses lies in the different characters of the learners. The GLA/FTNONFIN learners came up with five different analyses. The GLA/TROCHAIC-group came up with three analyses (a subset of the ones that the GLA/FTNONFIN learners came up with), while all the CD learners came up with two analyses (again a subset). This suggests that the kind of learning strategy has a bigger impact in the resulting variation than the difference in constraints.

While all of the learners were able to assign stress correctly to forms of two to four syllables, they did not uniformly transfer this stress pattern to forms that they have not been trained on. Eighty-six of the GLA learners transferred the stress pattern they applied to di- to quadrisyllabic forms to longer forms (forms with five to seven syllables) and to forms that are not attested in Pintupi (forms with long vowels in non-initial position). None of the CD learners applied this stress pattern to unheard forms. Most of them tended to stress long vowels that occurred anywhere in the word, i.e. their grammar showed a tendency towards weight-sensitivity. These generalizations could occur because the data that the learners have been trained on do not give enough evidence for a complete weight-insensitive analysis of Pintupi, since primary stress is always on the initial syllable of a word, and long vowels only occur in initial position and are therefore always stressed.

5.9 Conclusions

With respect to the different constraint sets, neither FTNONFIN nor TROCHAIC can be excluded as the constraint on trochaic feet. TROCHAIC learners came up with less different analyses than FTNONFIN learners.

Another effect became apparent in the simulations of acquisition here. An extensive list of constraints can complicate learning (as could be seen in the simulations with FTBIMORAIC in chapter 4), but it can also facilitate learning: one constraint not directly applying to the phenomenon can substitute the effect of another constraint crucial for the analysis: an analysis using TROCHAIC needs FTBIN and *CLASH to be higher-ranking so that disyllabic feet can surface. An analysis with FTNONFIN can take over the role of FTBIN: if FTNONFIN is ranked above PARSE feet are naturally disyllabic. Final syllables are unfooted not because they are too small, but because they would violate high-ranking FTNONFIN. This applies only to languages with trochaic feet; in iambic languages, FTBIN might still make a difference. It looks like OT constraints in their present form overlap to a certain extent, resulting in redundancy.

Simulations on the learnability of languages in an OT framework gives linguists the possibility of testing claims made in cross-linguistic research and the study of child language acquisition. Learnability limits the amount of e.g. possible stress systems in a different way than factorial typology does. While factorial typology is the set of all possible rankings of constraints that result in different languages, learnability limits the typology of all possible languages by restricting the range to the constraint rankings that are learnable (see also Boersma 2003).

In sum it can be said that learners of one and the same language may not end up with exactly the same grammar. This partly meets claims made by e.g. Mohanan (1992) and Yip (2003), who propose that speakers may vary in their grammars, yielding slightly different overt outputs, and still be able to communicate. The virtual learners here were exposed to the same data tokens, with the only difference that they encountered the data in a different order, and ended up with five different analyses of hidden structures. Their overt output was the same, though, which means that not only communication is guaranteed, but also that the speakers still speak the same variety of their language.