TWO PATHS – ONE GOAL: VOWEL HARMONY IN THE ACQUISITION OF HEBREW

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1 Introduction

There is much discussion in the literature on the acquisition of vowel harmony in languages with productive harmony systems (Leiwo et al. 2006 for Finnish, Altan 2007 for Turkish, among others). There is, however, little discussion on vowel harmony in languages *without* an active harmony grammar. In Ben-David's (2001:148) study of Modern Hebrew (henceforth: Hebrew) acquisition, final syllable doubling, resulting in identical syllabic nuclei in the final and penultimate syllables, is mentioned as the first stage of disyllabic productions. When additional syllables are added, the vowel is copied. This doubling is unaffected by vowel quality (Ben-David 2001:149) or stress (Ben-David 2001:151), and is not directly attributed to vowel harmony, but rather to a general preference for reduplicated forms and faithfulness to word-final syllables (Ben-David 2001:150). Mintz and Walker (2006) mention a role that vowel harmony possibly plays in the segmentation of strings in the acquisition of English, hypothesising that infants may show a universal predisposition to use harmony as one of their segmentation cues. In this paper, I not only show that such a predisposition exists in Hebrew, but that the acquiring infant's initial state has an active harmony grammar.

Following Ben-David's (2001) findings with respect to reduplication and doubling and Mintz and Walker's (2006) claims regarding English acquisition, I argue that vowel harmony is, in fact, utilised by the acquirer in order to facilitate production before the acquisition of all the segments has been completed. The acquisition of vowels in Hebrew is much faster than that of consonants (Ben-David 2001:271), so by the time infants start producing disyllabic forms, the vowels have more or less been acquired, making evidence for segmentally-motivated vowel harmony relatively scarce, and subsequently resulting in very little research in this area. In order to find productive vowel harmony, one needs to collect data from the earliest stages of acquisition, to ensure that one does not overlook the extremely small amount of relevant data.

The question this paper addresses concerns the universal status of vowel harmony implied by Mintz and Walker (2006). Does vowel harmony play a role in the acquisition of non-harmony languages such as Hebrew? If so, this would suggest the universality of vowel harmony, as children acquiring such languages could not have got their harmony grammar based on input from the ambient language. Note, the universal nature of vowel harmony was also proposed in Cohen (2010, 2011), but this refers to adult grammars in which harmony may surface in parts of the lexicon's periphery, such as in loanwords.

The goal of this paper is to demonstrate that vowel harmony, a non-native process in Hebrew, nevertheless applies systematically during acquisition. The infants may follow different paths in their grammatical development on the way to the ultimate goal, a final status in which there is no productive vowel harmony. Since vowel harmony is not supported by the ambient language, this suggests that it is universally motivated.

The paper is structured as follows. In §2, I review harmonic forms in the native Hebrew lexicon and establish that Hebrew has no productive harmony grammar. In §3, I present vowel harmony data from two Hebrew acquiring infants, and discuss the interaction among various factors known to affect vowel harmony. This is followed by a formal analysis within Optimality Theory, in §4 and §5. I then address the issue of variation briefly, before concluding in §6.

2 Harmonic Forms in the Native Hebrew Lexicon

Various phenomena in the native Hebrew lexicon have been attributed to vowel harmony. These might suggest a productive vowel harmony system, something which would then be unsurprising to find in acquisition. However, these phenomena, briefly outlined below, can be shown to be neither vowel harmony nor productive.

A quantitative analysis of Bolozky and Becker's (2006) Hebrew corpus shows that there are 6429 disyllabic nominal forms, 1441 (roughly 22%) of which have identical vowels (henceforth, harmonic forms) as follows:

(1) Harmonic forms in the Hebrew lexicon

Vowels	**Total**
a-a	890
e-e	428
i-i[1]	60
o-o[2]	44
u-u[3]	19
Total	1441

[1] 25 of these are monosyllabic bases with the *–im* masculine plural suffix, 20 are loanwords, and only 8 are commonly occurring words.
[2] 32 of these are loanwords, 2 are monosyllabic bases with the *–ot* feminine plural suffix.
[3] At least 9 are loanwords, 2 are monosyllabic bases with the *–ut* derivational suffix.

In the 5-vowel system of Hebrew, if the vowels in disyllabic forms were selected by chance, we would expect ~20% to be harmonic, and this is more or less what we get, i.e. the distribution of harmonic forms in the lexicon is no better than chance. This result does not take into consideration various suffixed monosyllabic bases in which the suffix and base have identical vowels (e.g. the masculine plural morpheme *–im* added to a monosyllabic base with the vowel *i* - *ʃi*ˈʁ-*im* 'songs'), nor does it separate loanwords from native lexical items, or consider token frequencies. Cases cited in the literature as being products of vowel harmony in Hebrew, such as segholates (Bat-El 1989:180, Bolozky 1995 – e.g. ˈ*melex* 'king', ˈ*ʃaʕaʁ* 'gate'), cross-guttural harmony and cross glottal harmony (McCarthy 1994, Kawahara 2007 – e.g. */jədaʕnuka/* → *jədaʕənuka* → *[jədaʕaˈnuka]* 'we knew you'), and plural suffixes (Becker 2009:109 – e.g. the masculine *mot* 'pole' taking the feminine plural suffix *–ot* forming *moˈt-ot* 'pole-s' and not **moˈt-im*), were shown in Cohen (2011) to largely be residual effects from Biblical Hebrew or products of certain noun templates which are inherently harmonic, rather than being products of an active vowel harmony system.

Observing the above, it appears that there is indeed no productive vowel harmony in Hebrew. Therefore, children acquiring the language are exposed to a distribution of harmonic forms which is no better than chance and unsystematic, i.e. they are not exposed to an active harmony system.

3 Data[4]

In order to pinpoint the effects of various factors on vowel harmony, only disyllabic productions of two typical Hebrew-acquiring children, RM (female) and SR (male), were extracted and analysed. Furthermore, only forms which were completely harmonic (i.e. identical vowels, not just vowels agreeing in some feature) were considered.[5] This enables us to tease apart the roles of various competing factors discussed.

The data are all organised according to the developmental periods laid out in Adam and Bat-El (2008, 2009), which reflect the size of the child's acquired lexicon as an indicator of the developmental stage, rather than the child's age. Adam and Bat-El show this to be a better indicator of developmental progress than chronological age. The data were examined up until the eighth developmental period. After this period, the presence of harmony in the child's productions was no different from the ambient language. The developmental periods are shown in the following table (2):

[4] The data used in this study are drawn from the language acquisition project directed by Outi Bat-El and Galit Adam at Tel-Aviv University.

[5] An anonymous reviewer mentioned that the harmonic forms may not, in fact, be the result of vowel harmony, but rather could be the result of reduplication or some other phonological process. It makes no difference, however, whether the vowel copying is a result of reduplication or vowel harmony as what is crucial here is the factors selecting the sponsor vowel and the target vowel.

(2) Developmental periods in acquisition

Period	Cumulative Attempted Targets	Ages	
		SR	RM
1	~10	1;02.00-1;03.05	1;03.27-1;04.09
2	~50	1;03.14-1;04.17	1;04.18-1;05.29
3	~100	1;04.24-1;05.08	1;06.05-1;08.01
4	~150	1;05.15-1;05.21	1.08.07-1.09.18
5	~200	1;05.29-1;06.02	1.09.27-1.10.13
6	~250	1;06.12-1;06.20	1.10.28-1.11.18
7	~300	1;06.26-1;07.02	1.11.25
8	~350	1;07.09	2;00.02-2;00.09

Complete tables of SR and RM's productions are provided in Appendices I and II respectively. A general description of the children's productions appears in the following §3.1. The two infants are compared with respect to various factors influencing vowel harmony: stress (§3.2), directionality (§3.3) and vowel quality (§3.4), followed by a discussion and comparison in §3.5.

3.1 Description of the Children's Vowel Harmony

In SR's disyllabic productions during Period 1 (henceforth: P1), only three vowels were attempted and produced consistently, *a, u, i*. Note, all vowels are produced in monosyllabic forms during Period 1. The vowel *e* was only attempted and produced for the word *ˈine* 'here'. The vowel *o* was not produced at all. SR only started to attempt and produce all five vowels in P2, and even here, *o* was severely restricted, (both attempts and productions), surfacing only for *ˈʁoni* 'Ronny (name)' and *ˈalo* 'hello'. The vowel *a* was the only anchor (i.e. underlying sponsor) in harmonic forms in P1 (/taˈpuax/ [ˈbaax] 'apple'). The vowel *u* first appears as an anchor in P2 (/ˈtuki/ [ˈkuku] 'parrot'), *i* in P3 (/leoˈʁid/ [ˈʔijit] 'take down'), *o* in P7 (/ˈejfo/ [ˈʔofo] 'where') and finally *e* in P8 (/jaˈʃen/ [ʔeˈθen] 'asleep'). The following table summarises all disyllabic productions by SR.

(3) SR's disyllabic productions and harmony

Period	Tokens						Types	
	Total 2σ Forms	**Total Harmonic Forms**		**Total Vowel Harmony**			**Total Harmonic Forms**	**Total Vowel Harmony**
	#	**% (of total)**	#	**% (of harmonic forms)**	**% (of total)**	#	#	#
1	131	61.8	(81)	2.5	1.5	(2)	5	1
2	251	39.0	(98)	14.3	5.6	(14)	19	8
3	227	26.0	(59)	32.2	8.3	(19)	17	5
4	160	28.8	(46)	41.3	11.9	(19)	24	7
5	205	41.0	(84)	8.3	3.4	(7)	34	3
6	190	30.5	(58)	10.3	3.2	(6)	26	4
7	382	35.6	(136)	8.8	3.1	(12)	55	8
8	332	32.8	(109)	11.9	3.9	(13)	41	11

The above table (3) presents the number of disyllabic forms produced, the number of harmonic forms out of these disyllabic forms, and the number of these harmonic forms which, in fact, are a reflection of vowel harmony. The overall occurrence of harmonic forms during P1 is 61.8% (81/131), only 2.5% (2/81) of which are the result of vowel harmony. This shows a clear preference for selecting targets which are harmonic to begin with. Selectivity plays a role here, as harmonic targets are more likely to be selected than disharmonic targets. Such a role of selectivity has been found for Hebrew phonology (Ben-David 2001:342, Bat-El this volume, Becker this volume) and morphology (Lustigman 2007, this volume), as well as other languages (Schwartz and Leonard 1982, Schwartz et al. 1987, Drachman 1973, Ferguson et al. 1973, Stoel-Gammon and Cooper 1984, Mintz and Walker 2006, to name a few). This selectivity indicates a preference for harmonic forms (recall, this preference is not supported by the language itself), which decreases after P1, as selectivity loses its influence on target selection. However, the percentage of tokens in which active harmony takes place rises progressively from the first period, peaking at P4, when 41.3% (19/46) of all harmonic forms are the product of vowel harmony. It then drops to 8.3% (7/84), more or less where it remains until P8. Throughout the 8 periods, the frequency of harmonic forms produced by SR was well above Hebrew's ~20%.

Since Hebrew provides no evidence for a preference for harmonic forms, SR's preference for such forms must be universally motivated (Cohen 2011). The effect of this universal principle, which is not supported by the ambient system, can only surface during acquisition before the ambient system has "taken over", i.e. during the earliest stages of acquisition (Rose 2000, Adam and Bat-El 2009), before the children have acquired sufficient contradictory evidence not supporting the principle. Note, in adult languages, universal preferences not supported by the native grammars might surface, but largely only in the lexical periphery, such as loanwords, blends and acronyms (Shinohara 2004, McCarthy and Prince 1994, Bat-El 2000, Berent et al. 2009, Kenstowicz 2004, Cohen 2010, 2011).

RM attempted and produced all vowels from P1. There were no disyllabic harmonic forms in P1. The vowel *a* was the only anchor in harmonic forms in P2 (/ˈpeʁax/ [ˈhawa] 'apple'), *e*, *u* and *i* in P3 (/maˈkel/ [jeˈken] 'stick' ; /bakˈbuk/ [puˈpu]

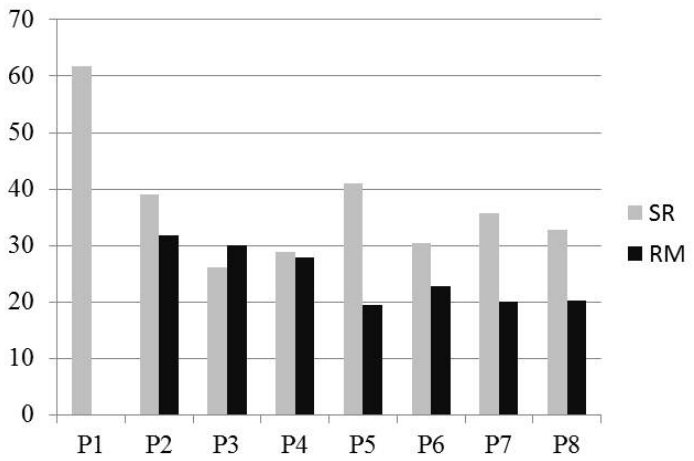
'bottle' ; /ˈine/ [hiˈniʃ] 'here'), and finally *o* in P4 (/ipaˈʁon/ [oˈboj] 'pencil'). The following table summarises all disyllabic productions by RM:

(4) RM's disyllabic productions and harmony

Period	Token						Type	
	Total 2σ Forms	Total Harmonic Forms		Total Vowel Harmony			Total Harmonic Forms	Total Vowel Harmony
	#	% (of total)	#	% (of harmonic forms)	% (of total)	#	#	#
1	7	0	(0)	0	0	(0)	0	0
2	126	31.7	(40)	7.5	2.4	(3)	15	2
3	247	30.0	(74)	10.8	3.2	(8)	23	7
4	140	27.9	(39)	25.6	7.1	(10)	24	8
5	124	19.4	(24)	25	4.8	(6)	17	4
6	299	22.7	(68)	7.4	1.7	(5)	40	5
7	155	20.0	(31)	19.4	3.9	(6)	21	5
8	320	20.3	(65)	12.3	2.5	(8)	48	8

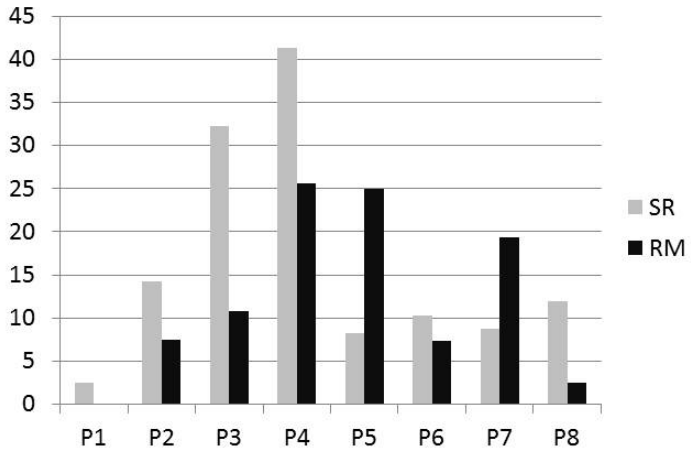
During P1, RM barely produces disyllabic forms (and of course produces no harmonic forms whatsoever). Harmonic forms are attempted and produced more during P2-P4 (around 30% of all forms produced) dropping to around 20% during P5-P8, which is more or less the expected rate for Hebrew. Selectivity plays a lesser role for RM than for SR. Non-harmonic forms undergoing harmony gradually rise, peaking at P4, where 25.6% of all harmonic forms produced are the product of vowel harmony. This dips to 7.4% (5/68) in P6. RM's pattern is similar to that of SR, with both children's harmony increasing towards P4, where it peaks, and gradually dropping from P5 onwards, as the following diagram (5) shows.

(5) Harmony - % of vowel harmony out of all harmonic forms



Selectivity also plays a role for both infants during the initial stages, more so for SR than for RM. More harmonic forms are attempted and produced, as both show a preference for harmonic forms (selectivity), as shown in the following diagram (6):

(6) Selectivity - % of harmonic forms out of all disyllabic forms



3.2 Harmony-Stress Interaction

Vowel harmony may interact with stress (e.g. Revithiadou et al. 2006). There are two logically possible ways for harmony to interact with stress. The first, the stressed syllable may serve as the anchor of the harmony, with the unstressed vowel serving as the target of the harmony and changing accordingly. The second (unattested crosslinguistically, though logically possible), the unstressed syllable may serve as the anchor of the harmony, with the stressed vowel being targeted. When observing the data, the question is whether vowel harmony interacts at all with the word's stress pattern or not. The following table (7) presents data relevant to harmony-stress interaction:

(7) Harmony-stress interaction (types)

Period	SR			RM		
	Total VH	Stressed Anchors		Total VH	Stressed Anchors	
	N	%	N	N	%	N
1	1	0	(0)	0	0	(0)
2	8	37.5	(3)	2	50	(1)
3	5	80	(4)	7	71.4	(5)
4	7	71.4	(5)	8	87.5	(7)
5	3	33.3	(1)	4	100	(4)
6	4	75	(3)	5	100	(5)
7	8	75	(6)	5	60	(3)
8	11	54.5	(6)	8	62.5	(5)

If stressed anchors are selected 50% of the time, then stressed anchors are not preferable to unstressed anchors. For SR, there seems to be no obvious correlation between stress and harmony. If there is some interaction between the two, it certainly does not develop with any consistency over the eight periods. Harmony and stress appear to interact in P3, P4, P6 and P7, where the stressed syllable serves as the anchor in most cases. However, the interaction between the two is no better than chance in P8. In P1, P2 and P5, the unstressed syllable serves as the anchor in most cases. There appears to be no systematic interaction between stress and anchor selection.

For RM, the picture is completely different. Here, the interaction between stress and harmony is clear. Initially, during P2, no preference was given to stressed anchors over unstressed anchors. However, this changed dramatically during P3, when stressed anchors were preferred, rising in P4, and peaking in P5-P6, where all anchors were stressed, gradually dropping thereafter. A certain pattern emerges here, showing a clear development in the interaction between stress and harmony in RM's acquisition.

3.3 Harmony-Directionality Interaction

Vowel harmony may interact with directionality (i.e. positional prominence, Kiparsky 1997, Zoll 1998, Gordon 2004, Smith 2004, Revithiadou et al. 2006 among others), with either the righthand vowel (e.g. SR in P2: /ˈopa/ [ˈhapa] 'upsy daisy' ; RM in P2: /ˈpeʁax/ [ˈhawa] 'flower') or the lefthand vowel (e.g. SR in P2: /ˈtuki/ [ˈkuku] 'parrot' ; RM in P3: /pʁaˈxim/ [paˈxa] 'flowers') being the preferred anchor. The following table (8) presents the effect directionality has on harmony:

(8) Harmony-directionality interaction (types)

	SR			RM		
Period	**Total VH**	**Righthand Anchors**		**Total VH**	**Righthand Anchors**	
	N	**%**	**N**	**N**	**%**	**N**
1	1	100	(1)	0	0	(0)
2	8	50	(4)	2	100	(2)
3	5	100	(5)	7	71.4	(5)
4	7	85.7	(6)	8	87.5	(7)
5	3	66.7	(2)	4	100	(4)
6	4	100	(4)	5	100	(5)
7	8	100	(8)	5	40	(2)
8	11	72.7	(8)	8	62.5	(5)

For both infants, directionality has an overwhelming effect on harmony. For SR, the anchor is on the right side in all cases in P1, P3, P6, P7, and in most cases in P4, P5 and P8. The only exception is P2, where the effect of directionality seems no better than chance. RM patterns similarly to SR. Directionality has an overwhelming effect on harmony in P2, P5, P6, with the anchor being on the right side in all cases. In P3

and P4, a righthand anchor was preferred in most cases, but after P6, the effect of directionality seems to drop to not much better than chance.

Both infants' clear preference for a righthand anchor is supported by the literature. The prominence of the right edge in acquisition is well documented (Ota 2006, Smith 1973, Ben-David 2001, Adam 2002, Dinnsen and Farris-Trimble 2008, to name a few) and could very well be playing a role here.

3.4 Harmony-Quality Interaction

The selection of the anchor of the harmony may be affected by vowel quality. This could be determined on the basis of sonority (e.g. *a* > *o* > *i* – Revithiadou et al. 2006), or on the basis of height and dispersion (e.g. high > mid > low – Cohen 2011). Note, as mentioned in §3.1, SR did not produce mid-vowels during P1, and barely did so during P2. Since I argue, following Ben-David (2001), that vowel harmony is utilised by the acquirer in order to facilitate production before segmental acquisition has been completed, it is not surprising to find some effect of vowel quality on anchor selection for SR.

The following table (9) shows the correlation between various vowel qualities and harmony for anchors (0 values deleted, maximal values in each row shaded in bold):

(9) Harmony-quality interaction: Anchors (number of types)

Period	SR						RM					
	Total VH	a	u	i	e	o	Total VH	a	u	i	e	o
1	1	**1**										
2	8	**7**	1				2	**2**				
3	5	**3**	1	1			7	1	**2**	**2**	**2**	
4	7	**3**	1	**3**			8	**3**		1	**3**	1
5	3	**2**		1			4	1			1	**2**
6	4	**2**		**2**			5		2		**3**	
7	8	2	2	**3**		1	5	**2**		1	**2**	
8	11	**7**	2	1	1		8	2	1	1	**4**	

For SR, during P1-3, the preferred anchor is clearly *a*. This apparent preference seems to continue throughout the eight stages, though high vowels play a considerable role from P3, with mid-vowel anchors only being selected from P7.

For RM, on the other hand, there is no clear interaction between vowel quality and anchor selection.

Recall that SR did not produce mid-vowels at all until P3, so the effect of vowel quality on anchor selection is not surprising. RM, on the other hand, produced all vowels from P1, which might explain why anchor selection is unaffected at all by vowel quality for RM.

The following table (10) shows the correlation between various vowel quality and harmony for targets:

(10) Harmony-quality interaction: Targets

Period	SR						RM					
	Total VH	a	u	i	e	o	Total VH	a	u	i	e	o
1	1		**1**									
2	8		1	2	2	**3**	2				**1**	**1**
3	5	1		1		**3**	7	**3**		**3**	1	
4	7	2		1		**4**	8	**4**	1			3
5	3					**3**	4	1			**2**	1
6	4	1				**3**	5	**5**				
7	8	**3**	1		2	2	5	**2**			1	**2**
8	11	1	1	**3**	**3**	**3**	8	**3**		2	**3**	

For SR, as far as targets go, *o* is clearly a preferred target (shaded) for harmony, with other vowels being targeted less frequently than *o*. For RM, mid-vowels were the only targets in P2 (in both cases, *a* is the anchor), which might indicate the preference of *a* over mid-vowels during the very early stages. This preference, however, disappears from P3 onwards, showing no clear quality-based preference similar to SR's. Since RM produces all vowels early on, this may very well restrict the role of vowel quality in anchor/target selection.

In Ben-David's (2001:272) study, the order of the vowel acquisition found for acquirers of Hebrew is roughly *a>i,u>o,e* (where a comma indicates the absence of precedence relations), a scale which coincides with SR's data. Assuming acquisition order is, inter alia, motivated by some notion of markedness, and harmony reflects this same acquisition order, it would suggest that the relevant factor affecting harmony is this notion of markedness. Dromi et al. (1993) present even a rougher markedness scale than Ben-David's, with *a,i* and *u* being produced before *o* and *e*. Based on this previous research and the current harmony data, it is possible to construct a developmental scale of sorts: *a>u>i>e>o*, which reflects the ability of the various vowels to serve as anchors. This may be a complex scale resulting from the interaction among various features such as sonority, height and dispersion. However, for simplicity's sake, I will refer to the harmony-quality interaction scale henceforth as markedness. Note, that such a markedness scale is not surprising, given that it plays a role in target selection and production for SR from P1, regardless of its specific effect with respect to harmony.

3.5 Summary and Discussion

Generally speaking, both infants attempt and produce more harmonic forms during earlier periods, with both children peaking in P4. After P4, there is a turning point. Here, selected forms are of all types, and only newly introduced lexical items tend to harmonise, and even then, only for a brief period, before being produced faithfully. Note, all harmonic forms produced were also produced faithfully. Furthermore, all harmonising forms are produced the same way. For example, *hipopoˈtam* 'hippopotamus' would potentially allow for *toˈtom* or *taˈtam*, but we only get the latter. All of this indicates that some harmony system does indeed play a role in the

infants' acquisition, one which gradually diminishes as the infant becomes more faithful to the target language, which does not have vowel harmony.

The apparent inconsistencies with some of the data become considerably less problematic when the interaction among the three criteria is examined.

Recall the following observations. Stress seems to play no role for SR (we'll get back to this shortly…). Directionality (right-to-left) had a considerable effect in almost all stages (P2 being the exception). Markedness also played a role, with more inconsistencies later in the development.

However, the following observations are immediately evident from SR's data in Appendix I. Competing factors may clash, and when they do so, markedness is only violated if both stress and directionality are satisfied. The cumulative effect of stress and directionality is the only justification for the violation of markedness. If stress and directionality do not agree with one another, then markedness is satisfied.

For SR, during P1, the only instance of harmony is determined via markedness and directionality, with the unmarked *a* serving as the anchor in the righthand, unstressed syllable. In P2, every single instance of harmony prefers the unmarked vowel, often contradicting both of the other factors, showing a clear preference for markedness over directionality and stress. In P3, the only instance in which markedness is violated is one in which stress and directionality are satisfied. In P4, there are two instances in which markedness is violated. Once again, stress and directionality are both satisfied here. This systematic behaviour continues throughout all eight periods. Harmony is governed by markedness. Markedness can only be violated if both stress and directionality are satisfied. First of all, this shows that all three factors do indeed play some role, but that of markedness is more dominant. Note, there are only two instances in which markedness and stress are violated, giving preference to the directionality. The first, /ˈefo/ → [ˈofo] 'where' (both mid vowels) and the second /ˈtuki/ → [ˈtiki] (both high vowels). In cases in which markedness is a clear issue (low vs. mid/high or high vs. mid), there are no exceptions to the markedness preference.

With respect to the various factors affecting harmony, markedness (*a*>*u*>*i*>*e*>*o*) and directionality (R>L) seem to play a considerable role for SR. Stress, on the other hand, seems to play a lesser role in the selection of the anchor. SR's initial productions and harmonies are strongly affected by markedness. However, once all segments have been acquired, directionality starts to play a substantial role too.

For RM, the picture is somewhat different. Similarly to SR, target harmonic forms are attempted and produced more earlier on. Later, other forms are attempted, but are forced to harmonise in many cases, up until the end of P4, where there is a turning point, and the role of harmony starts to decline. Also similarly to SR, the harmonic forms produced were produced faithfully. While production is variable, with forms being produced both faithfully and with vowel harmony, harmony is not variable, and all the harmonic forms of each word are identical. There was only a single exception: the target form *ˈine* 'here' was produced as *ˈene* and *ˈini* interchangeably. Harmony plays a systematic role which gradually diminishes as she becomes more faithful to adult forms.

However, RM differs from SR in the role of the various factors influencing harmony. For RM, the relevant factors are primarily prosodic (stress, directionality) rather than segmental (markedness). Stressed syllables and righthand syllables (which usually coincide in Hebrew) are preferred anchors, with no obvious influence of markedness.

However, this is misleading. A closer examination of RM's data shows that in all cases in which the stress factor contradicted the directionality factor (i.e. where the stressed syllable does not coincide with the righthand syllable), the anchor selected was the least marked vowel *a*. Furthermore, in the cases in which the selected anchor was neither stressed nor on the right, the anchor selected was *a* and the target was a mid-vowel (most marked). This may suggest that although prosody is the most important factor for RM, in the event of a contradiction between the two prosodic factors, or in the event that the factors do not play a role, markedness kicks in, selecting *a* anchors over all others.

4 Towards a Formal Analysis

In this section, I incorporate the above generalisations into a formal grammar of vowel harmony within Optimality Theory (Prince and Smolensky 1993/2004). My analysis is within an Optimal Domains Theoretical approach (ODT, Cole and Kisseberth 1994, Cassimjee and Kisseberth 1999). Since the infants exhibit different behaviours with respect to the effect of the relevant factors on vowel harmony, they should have different developmental grammars. As I will show during the remainder of this section, the two infants do have different developmental grammars, but the differences are the result of different rankings of the same constraints.

4.1 Setting up the Harmonic Domain

Harmony is a requirement for a feature *F* to be realised on all sponsors within a domain *D*. How harmony is realised is a result of the interaction among constraints on the structure of domains and constraints on the realisation of *F*.

For features to be realised, they have to be within a domain. Domain construction is achieved via alignment constraints, which designate the domain's edges.

(11) ALIGN (ANCHOR, L/R ; F-DOMAIN, L/R) (Cole and Kisseberth 1994)

The anchor of a feature is aligned with the domain's L/R edge

This constraint, consisting of two members (one for each edge), sets up the left and right edges of the domain. In a situation in which there is no harmony, for example in the adult grammar of Hebrew, the left and right edges of the domain are aligned with the left and right edges of the segment, and every feature is realised on its underlying anchor. The alignment constraints militate against vowel harmony.

However, if, due to constraint interaction, one of the domain's edges shifts, then a feature may be realised over a larger span than a single segment, and the domain expands. One type of constraint which could trigger the domain's expansion sets a lower limit on the domain's size. Alternatively, the requirement could be for a bimoraic domain, such as a foot (Halle and Vergnaud 1978, Harris and Lindsey 1995, van der Hulst and van der Weijer 1995, McCarthy 2004 and more). For simplicity's sake and due to any lack of evidence preferring one analysis over the other, I adopt the following constraint requiring domains to be larger than monosyllables. Effectively, this is equivalent to constructing a bimoraic domain while assuming

constraint violation is minimal (economy, do only what is necessary; Prince and Smolensky 1993/2004):

(12) *MONOD (Cassimjee and Kisseberth 1999)

Domains cannot be monosyllabic

On the one hand, features would like to align themselves with their anchors. On the other hand, there are both articulatory and perceptual motivations for features to spread beyond the boundaries of their anchors. If the constraint forcing domains to be larger than a single syllable outranks those setting up the domain edges, then harmony could occur. The (in)ability of domains to spread onto neighbouring vowels is controlled by the interaction between the alignment constraints and the constraint militating against monosyllabic domains. In a non-harmony grammar (e.g. adult Hebrew), the ranking is ALIGNL/ALIGNR >> *MONOD, and no harmony occurs. In a harmony grammar (e.g. the grammar of SR and RM during P4), *MONOD is ranked above one (or both) alignment constraints, forcing the violation of the lowest ranked alignment constraint and the expansion of the domain.

However, it is insufficient to construct domains in order for harmony to occur. We have to ensure that the harmonic features are realised on all sponsors (i.e. vowels) within a domain.

(13) REALISEF (similar to Cole and Kisseberth's (1994) EXPRESS)

Underlying features must be realized within their domain

This constraint ensures that features are realised on all sponsors within the anchor's domain. Since consonants are not potential sponsors of the vowel features, they vacuously satisfy REALISEF.

Of course, realising the underlying features of one vowel within a bimoraic domain would cause the other vowel within the domain *not* to have its features realized. Assuming domains must be bimoraic (otherwise harmony would not occur), how do we determine which vowel is the one to expand its domain, and which vowel, in effect, "sacrifices" its underlying features? Otherwise phrased, what are the factors determining the relative faithfulness of vowels to their underlying features in instances of harmony? Three such factors are those discussed earlier, namely stress, directionality and markedness. The interaction among the domain construction and feature realisation with these three factors is discussed in §4.2 (stress), §4.3 (directionality) and §4.4 (markedness).

4.2 Harmony and Stress

The interaction of harmony and stress is a result of constraints requiring the stressed vowel to be more faithful to its underlying features than other vowels (Steriade 2001/2008, Kenstowicz 2007 and more):

(14) IDENTF(STRV)

Stressed vowels are faithful to their underlying features

(15) IDENTF(V)

Vowels (in general) are faithful to their underlying features

These constraints interact with one another. All other things being equal, stressed vowels are more faithful than unstressed vowels, implying the fixed ranking: IDENTF(STRV) >> IDENTF(V). Since all cases of harmony require the violation of IDENTF(V), my analyses only refer to IDENTF(STRV)

4.3 Harmony and Directionality

An additional characteristic of vowel harmony is that it typically operates in a certain direction (leftward or rightward). The direction of the spreading is controlled by the relative ranking of two alignment constraints, ALIGNL and ALIGNR, which determine the "default" directional preference. For example, if ALIGNR>>ALIGNL, then domains will tend to spread leftwards in order to satisfy *MONOD.[6]

4.4 Harmony and Markedness

Generally speaking, grammars prefer to realise unmarked underlying segments more so than marked underlying segments, when given the choice. Assuming the expansion of the domain to satisfy *MONOD, when deciding whether to select a marked or unmarked anchor, all other things being equal, grammars would go with the unmarked anchor. A markedness scale (such as the one suggested in §3.4) is reflected in the following constraint ranking:

(16) MARKEDNESS

*o >> *e >> *i >> *u >> *a

Henceforth, I do not refer to the whole scale. Rather, I use the constraint MARKEDNESS, a violation of which would indicate the selection of a more marked anchor in a given situation. This constraint would naturally compete with IDENTF(V). However, if due to harmony, one of the vowels has to sacrifice its features, it would be the more marked vowel.

[6] Of course, if ALIGNL>>MONOD and ALIGNR>>MONOD, then there is no harmony at all.

5 The Developmental Path of a Harmony Grammar

5.1 SR's Grammatical Development

Recall the relevant generalisations from the development of SR's harmony (§3). The three factors interact in the following ways. Stress appears to be irrelevant with respect to determining the anchor of the harmony (hold this thought). Directionality, on the other hand, has an overwhelming effect, with the preferred anchor being on the right side. In all but two cases, when directionality and stress clash, directionality wins. The only two exceptions are cases in which markedness and directionality also clash, and then markedness wins (giving the "appearance" of stress winning). This would imply, at the very least, that ALIGNR, which requires anchors to be on the right is ranked higher than IDENTF(STRV), which requires the anchors to be stressed, as demonstrated in the following tableau (17) (Note, henceforth, deletion and consonant quality are ignored).

(17) SR's P1: *ta'puax* 'apple'

ta'puax	ALIGNR	IDENTF(STRV)
☞ 'baax		*
'buux	*!	

How do these factors interact with markedness? In SR's data, the preferred anchors (in descending order), are *a>u>i>e>o*, evident in all eight stages, reflected in the MARKEDNESS hierarchy **o>>*e>>*i>>*u>>*a*.

(18) SR's P4: *sevi'von* 'spinning top'

sevi'von	MARK(*o>>*i)	ALIGNR
☞ vi'vim		*
vo'vom	*!	

However, the interaction between MARKEDNESS and ALIGNR is, in fact, more complex. There are occasions in which directionality wins (assuming that the ranking of the markedness constraints is fixed). In the following tableau, ☛ indicates the candidate which is selected by the (incorrect) grammar, while ✓ indicates the candidate which was actually produced:

(19) SR's P3: *bak'buk* 'bottle' (first attempt)

bak'buk	MARK(*u>>*a)	ALIGNR
☛ ba'bak		*
✓ bu'buk	*!	

In all such cases, i.e. cases in which MARKEDNESS and ALIGNR clash and in which ALIGNR wins, MARKEDNESS also clashes with IDENTF(STRV). This suggests that the combined effect of ALIGNR and IDENTF(STRV) may be greater than that of MARKEDNESS. MARKEDNESS is violated only if *both* stress *and* directionality are satisfied. The cumulative effect of stress and directionality is the only justification for the violation of markedness. This could be achieved formally via two different

mechanisms, constraint weighting (Pater 2009, Smolensky and Legendre 2006, Prince and Smolensky 1993/2004: 236) or constraint conjunction (Kirchner 1996, Moreton and Smolensky 2002). Without advocating either approach, I demonstrate this interaction via constraint conjunction:

(20) SR's P3: *bakˈbuk* 'bottle' (second attempt)

bakˈbuk	ALIGNR&IDENTF	MARK(*u>>*a)	ALIGNR	IDENTF(STRV)
baˈbak	*!		*	*
☞ buˈbuk		*		

The conjoined constraint ALIGNR&IDENTF is the highest ranked constraint, and is only violated if both ALIGNR and IDENTF(STRV) are violated, giving the cumulative effect necessary. This shows that all three factors, including stress, do indeed play some role, but that of markedness is more dominant.

The ranking of the constraints militating against vowel harmony gradually overtakes that of the highest ranked constraints militating for vowel harmony as the language pattern – i.e. no harmony – takes force.

5.2 RM's Grammatical Development

SR and RM display different vowel harmony patterns during the various stages of their phonological development and the three relevant factors discussed (markedness, directionality, stress). These different behaviours, therefore, should be reflected in different constraint rankings, i.e. different harmony grammars.

Recall the generalisations regarding RM's data (§3). The factors influencing harmony for RM are primarily prosodic (stress, directionality) rather than segmental (markedness). Stressed syllables and righthand syllables (which usually coincide in Hebrew) are preferred anchors. A closer examination of the role of markedness shows that in *all* cases in which stress contradicts directionality (i.e. the stressed syllable does not coincide with the righthand syllable), the anchor selected was the least marked vowel *a*. Furthermore, in the cases in which the selected anchor was neither stressed nor on the right, the anchor selected was *a* (least marked) and the target was a mid-vowel (most marked).

Such an interaction would suggest that the constraint ranking for RM differs from that of SR. ALIGNR and IDENTF(STRV) outrank MARKEDNESS, however, the combined effect of MARKEDNESS with either of the other two constraints outweighs the effect of any single constraint:

(21) RM's P2: *ˈpeʁax* 'flower'

ˈpeʁax	ALIGNR&MARK (*e>>*a)	IDENTF(STRV)	ALIGNR	MARK(*e>>*a)
☞ ˈhawa		*		
ˈhewe	*!		*	*

5.3 Variation

In adult Hebrew, there is no productive harmony system. Therefore, ALIGNR/L, the constraints militating against harmony, outrank *MONOD, the constraint forcing harmony. For SR and RM, it is clear the *MONOD is ranked higher than at least one of the alignment constraints. Although this would explain why harmony takes place with SR and RM, it would fail to explain why harmony does not take place in all cases, but rather only in some cases, albeit considerably more than the language's general patterning of harmonic forms. Furthermore, as mentioned in §3.5, all cases of harmonizing forms are also produced faithfully, i.e. without harmony.

In a system in which constraints are strictly ranked, such variation is impossible. Variation would require the fluctuation in the ranking of *MONOD, which would vary in any given evaluation. This could be achieved via stochastic OT (Boersma 1997), a noisy harmonic grammar (Boersma and Pater 2008) or suchlike. This discussion is beyond the scope of this paper. Suffice it to say that the strict ranking presented in §4 reflects the general tendencies of the infants' grammars, and some mechanism of variation is necessary to cover the exceptional behaviours.

6 Discussion and Conclusions

The developmental paths of SR and RM shed light on the mechanism of the acquisition of the ambient language's grammar. The children start out at roughly the same point (the initial stage). While this point is universally conditioned, the ultimate goal is determined by the ambient language's grammar. The developmental path, however, is individual, with each infant pursuing a different route until reaching the final goal, the adult system.

Hebrew does not have productive harmony, yet the infants acquiring the language show a distinct preference for harmonic forms from the beginning of acquisition (selectivity). This suggests that harmonic forms are universally preferred. The infants then form some harmonic grammar in order to deal with disharmonic forms. However, the grammars they form differ from infant to infant as a result of the differing rates of prosodic and segmental development. SR, whose segmental development was slower than RM's, ranked constraints requiring unmarked vowels higher in his system than RM did, amplifying the role of markedness in SR's grammar. On the other hand, SR's prosodic development was rapider than RM's. Therefore, prosodically motivated preferences (the preference for the righthand syllable, the preference for the stressed syllable) play a lesser role for SR than they do for RM.

The infants harmony grammars are universally motivated, however, they stand in contradiction to the adult grammar in which there is no harmony. Therefore, they constantly adjust the grammars, eventually reaching the goal (ALIGNR/L>>*MONOD), but doing so along different developmental paths.

Appendix I: SR's Productions according to Periods and Criteria

Data are chronologically arranged, with only the first instance of each type in each period being mentioned. In the table, the period (P1-P8), the output, the input, the gloss, sponsor (S), target (T), markedness (Mark), stress (Str.), and right-to-left directionality factor (R>L).

Period	Output	Input	Gloss	S	T	Mark	Str.	R>L
P1	ˈbaax	taˈpuax	apple	a	u	Y	N	Y
P2	ˈaˈpax	itaˈpex	turn over	a	e	Y	N	N
	haˈwaa	ˈalo	hello	a	o	Y	N	N
	maˈma	ˈima	mother	a	i	Y	N	Y
	ˈhapa	ˈopa	upsy daisy	a	o	Y	N	Y
	ˈbama	kaˈdubɤ	ball	a	u	Y	N	N
	ˈkuku	ˈtuki	parrot	u	i	Y	Y	N
	ˈtatθaa	bejˈʦa	egg	a	e	Y	Y	Y
	taˈta	ipopoˈtam	hippopotamus	a	o	Y	Y	Y
P3	ˈtata	ipopoˈtam	hippopotamus	a	o	Y	Y	Y
	bukˈbuk	bakˈbuk	bottle	u	a	N	Y	Y
	ˈʔapam	ˈodpam	again	a	o	Y	N	Y
	ʔiˈjit	leoˈʁid	take down	i	o	Y	Y	Y
	gaˈgal	migˈdal	tower	a	i	Y	Y	Y
P4	ˈtatam	ipopoˈtam	hippopotamus	a	o	Y	Y	Y
	ˈʔaθaa	kivˈsa	sheep	a	i	Y	Y	Y
	ˈʔapam	ˈodpam	again	a	o	Y	N	Y
	biˈim	ʦipoˈʁim	birds	i	o	Y	Y	Y
	buˈbuk	bakˈbuk	bottle	u	a	N	Y	Y
	viˈvim	seviˈvon	spinning top	i	o	Y	N	N
	tiˈim	taˈim	tasty	i	a	N	Y	Y
P5	ˈʔapaam	ˈodpam	again	a	o	Y	N	Y
	laˈlaam	ʃaˈlom	hello/goodbye	a	o	Y	N	N
	piˈðim	ʦipoˈʁim	birds	i	o	Y	Y	Y
P6	iˈtθi	leoˈʦi	take out	i	o	Y	Y	Y
	taˈtam	ipopoˈtam	hippopotamus	a	o	Y	Y	Y
	ˈʔapam	ˈodpam	again	a	o	Y	N	Y
	tiˈnin	taˈnin	crocodile	i	a	N	Y	Y
P7	diˈsim	dolˈfin	dolphin	i	o	Y	Y	Y
	ˈʔofo	ˈejfo	where	o	e	N	N	Y
	kiˈʁiθ	kaˈʁiʃ	shark	i	a	N	Y	Y
	θiˈθim	suˈsim	horses	i	u	N	Y	Y
	tuˈnun	tamˈnun	octopus	u	a	N	Y	Y

Period	Output	Input	Gloss	S	T	Mark	Str.	R>L
	bukˈbuk	bakˈbuk	bottle	u	a	N	Y	Y
	ˈtatam	ipopoˈtam	hippopotamus	a	o	Y	Y	Y
	ʔaˈbaa	ˈzebʁa	zebra	a	e	Y	N	Y
P8	ʔaˈpax	aˈpex	turn over	a	e	Y	N	N
	ˈʔaxaʁ	aˈxeʁ	different	a	e	Y	N	N
	vaˈʁa	dvoˈʁa	bee	a	o	Y	Y	Y
	ˈʔapa	ˈopa	upsy daisy	a	o	Y	N	Y
	θaˈtθa	noˈʦa	feather	a	o	Y	Y	Y
	laˈla	simˈla	dress	a	i	Y	Y	Y
	suˈsu	ˈsusi	horse (dim.)	u	i	Y	Y	N
	ˈtiki	ˈtuki	parrot	i	u	N	N	Y
	ʔeˈθen	jaˈʃen	asleep	e	a	N	Y	Y
	puˈlu	jipˈlu	will fall	u	i	Y	Y	Y
	ˈʔaba	ˈzebʁa	zebra	a	e	Y	N	Y

Appendix II: RM's Productions according to Periods and Criteria

Data are chronologically arranged, with only the first instance of each type in each period being mentioned. In the table, the period (P1-P8), the output, the input, the gloss, sponsor (S), target (T), markedness (Mark), stress (Str.), and right-to-left directionality factor (R>L).

Period	Output	Input	Gloss	S	T	Mark	Str.	R>L
P1								
P2	ˈhawa	ˈpeʁax	flower	a	e	Y	N	Y
	tajˈda	toˈda	thank you	a	o	Y	Y	Y
P3	ˈene	ˈine	here	e	i	N	N	Y
	puˈpu	bakˈbuk	bottle	u	a	N	Y	Y
	hiˈniʃ	ˈine	here	i	e	N	Y	N
	paˈxa	pʁaˈxim	flowers	a	i	Y	N	N
	jeˈken	maˈkel	stick	e	a	N	Y	Y
	xuʦˈtun	xiˈtul	diaper	u	i	Y	Y	Y
	ˈbiipi	maˈʃpʁiʦ	squirt	i	a	N	Y	Y
P4	niˈni	aˈni	I	i	a	N	Y	Y
	ˈpaʷba	paaˈmon	bell	a	o	Y	N	N
	baˈʔja	kubiˈja	cube	a	u	Y	Y	Y
	oˈboj	ipaˈʁon	pencil	o	a	N	Y	Y
	hmˈdedet	mexaˈded	sharpener	e	a	N	Y	Y
	eˈʦeʦ	moˈʦeʦ	pacifier	e	o	Y	Y	Y

Period	Output	Input	Gloss	S	T	Mark	Str.	R>L
	beˈdek	mazˈleg	fork	e	a	N	Y	Y
	aˈdaf	od daf	another page	a	o	Y	Y	Y
P5	oˈpo	leˈpo	to here	o	e	N	Y	Y
	enˈʦeʦ	moˈʦeʦ	pacifier	e	o	Y	Y	Y
	maˈkaa	madbeˈka	sticker	a	e	Y	Y	Y
	xoˈjon	xaˈlon	window	o	a	N	Y	Y
P6	eˈxeʁ	aˈxeʁ	different	e	a	N	Y	Y
	eˈxeʁ	aˈxeʁet	differently	e	a	N	Y	Y
	tuˈtuu	kaˈduʁ	ball	u	a	N	Y	Y
	ʧeˈtet	mazˈleg	fork	e	a	N	Y	Y
	xuˈtuj	xaˈtul	cat	u	a	N	Y	Y
P7	ʁeˈje	aʁˈje	lion	e	a	N	Y	Y
	daˈjan	baˈlon	balloon	a	o	Y	N	N
	ˈini	ˈine	here	i	e	N	Y	N
	kaˈtam	kaˈtom	orange	a	o	Y	N	N
	eˈfe	jaˈfe	beautiful	e	a	N	Y	Y
P8	ˈini	ˈine	here	i	e	Y	Y	N
	ˈene	ˈine	here	e	i	N	N	Y
	nuˈnux	lixˈlux	dirt	u	i	Y	Y	Y
	peˈsek	masˈʁek	comb	e	a	N	Y	Y
	beˈʦek	mazˈleg	fork	e	a	N	Y	Y
	aˈxaax	aˈxeʁ	different	a	e	Y	N	N
	keˈneʃ	leikaˈnes	enter	e	a	N	Y	Y
	naˈma	naˈmeʁ	leopard	a	e	Y	N	N

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