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Simplification Strategies in the Acquisition of Consonant Clusters in Hebrew

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ABSTRACT

This thesis investigates the acquisition of consonant clusters, while focusing on the strategies applied by children in order to simplify the production of clusters. These strategies include cluster reduction ($_{\omega}$[CCV $\rightarrow$ $_{\omega}$[CV), vowel epenthesis ($_{\omega}$[CCV $\rightarrow$ $_{\omega}$[CVCV), coalescence ($_{\omega}$[CCV $\rightarrow$ $_{\omega}$[CV) and metathesis ($_{\omega}$[CCV $\rightarrow$ $_{\omega}$[CVC) (e.g. Greenlee 1974, Ingram 1976, Dyson and Paden 1983, Fikkert 1994, Gnanadesikan 1995/2004, Bernhardt and Stemberger 1998, Mcleod et al. 2001, 2001b, Ben-David 2001).

The thesis examines the strategies of cluster simplification in the acquisition of word-initial consonant clusters in Hebrew. The large variety of clusters in Hebrew relative to languages investigated in other studies of cluster acquisition allows further insight into the linguistic principles which affect the acquisition of clusters. The data are drawn from a longitudinal study of two typically developing Hebrew-acquiring children. These data allow an examination of cluster simplification from a developmental perspective.

Quantitative evaluation of the data mainly reveals that the different strategies of cluster simplification do not reflect different stages in the course of development as proposed in previous studies of Hebrew and other languages (e.g. Greenlee 1974, Ingram 1976, Fikkert 1994, McLeod et al. 2001, Ben-David 2001, Freitas 2003). Rather, they reflect multiple means to prevent the formation of clusters and are applied variably by children.

Regarding the strategy of cluster reduction, which is the prevalent simplification strategy, the study also finds that (a) most reduction patterns can be explained based on the interaction between contiguity requirements and onset sonority preferences, as found in previous studies of Hebrew acquisition (e.g. Ben-David 2001), although sonority plays a bigger role than previously reported; and (b) reduction patterns in *s*-clusters are inconsistent, and they do not necessarily indicate a difference between *s*-clusters and other clusters.

The data are analyzed in the framework of Optimality Theory (Prince and Smolensky 1993, McCarthy and Prince 1993a, b), which accounts for grammatical phenomena through the interaction among universal constraints. Variability in simplification patterns is accounted for within a theoretical model that allows gradient ranking of constraints and gradual learning (following Hayes 2000, Boersma 1997, 1998 and Boersma and Hayes 2001).

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1. Introduction

During periods of language acquisition, when children's grammar does not allow consonant clusters, children apply different strategies in order to simplify the production of clusters. These include cluster reduction ($_{\omega}$[CCV → $_{\omega}$[CV), vowel epenthesis ($_{\omega}$[CCV → $_{\omega}$[CVCV), coalescence ($_{\omega}$[CCV → $_{\omega}$[CV) and metathesis ($_{\omega}$[CCV → $_{\omega}$[CVC) (e.g. Greenlee 1974, Ingram 1976, Dyson and Paden 1983, Fikkert 1994, Gnanadesikan 1995/2004, Bernhardt and Stemberger 1998, Mcleod et al. 2001, 2001b, Ben-David 2001). These strategies fall under the general term 'cluster simplification', although this term is sometimes used to refer to a specific phenomenon whereby one or both of the cluster consonants are produced in a non-adult manner (e.g. Greenlee 1974, Mcleod et al. 2001).

The strategies of cluster simplification are the focus of this study, which explores the acquisition of word-initial consonant clusters in Hebrew. The data examined here are drawn from a longitudinal study of two typically developing Hebrew-acquiring children. These data allow an examination of cluster simplification from a developmental perspective.

Quantitative evaluation of the data mainly reveals that the different strategies of cluster simplification do not reflect different stages in the course of development as proposed in previous studies of Hebrew and other languages (e.g. Greenlee 1974, Ingram 1976, Fikkert 1994, McLeod et al. 2001, Ben-David 2001, Freitas 2003). Rather, they reflect multiple means of avoiding the production of clusters and are applied variably by children. Regarding the strategy of cluster reduction, which is the prevalent simplification strategy, the study also finds that (a) the role of sonority is greater than demonstrated in previous studies of Hebrew acquisition (Ben-David 2001); and that (b) differences in reduction patterns between *s*-clusters[1] and other clusters are not consistent enough to support a decisive conclusion regarding the status of *s*-clusters.

[1] Clusters in which the first consonant is a sibilant: the affricate /¢/ or any of the fricatives /s/, /z/ and /ʃ/.

The data are analyzed in the framework of Optimality Theory (Prince and Smolensky 1993, McCarthy and Prince 1993a, b), which accounts for grammatical phenomena through interaction among universal constraints. To account for variability in the application of simplification strategies, a model of gradient constraint ranking and gradual learning is adopted, following Hayes (2000), Boersma (1997, 1998) and Boersma and Hayes (2001).

The first part of the study provides a review of consonant clusters in Hebrew (§1.1), consonant clusters in language acquisition (§1.2) and previous studies of the acquisition of consonant clusters in Hebrew (§1.3). The second part presents the objectives of the current research (§2), the methods by which the data are examined (§3) and the theoretical framework adopted here (§4). The results of the study are presented and discussed in §5. This discussion addresses cluster simplification strategies and other phenomena identified in the children's productions (§5.1 - §5.10) and the variability in their application (§5.11). The last section (§6) is a conclusion.

1.1 Word-initial consonant clusters in Hebrew

Languages that allow the realization of consonant clusters usually restrict the possible combinations of the consonants in a cluster. Some of the restrictions are universal and others are language specific. There are two major universal constraints that affect onset consonant clusters in languages, the Sonority Sequencing Principle (SSP) and the Obligatory Contour Principle (OCP).

The SSP, in a version suggested in Blevins (1995), disallows sonority rise from the nucleus of the syllable to the margins, thus barring onset clusters in which the first consonant (C1) is more sonorous than the second consonant (C2). This version of the SSP allows sonority plateaus, which exist in Hebrew (see below in this section). Other more common versions require sonority fall from the nucleus to the margins (e.g. Selkirk 1984, Clements 1990, Parker 2002). A version of a sonority scale, drawn from Yavas and Gogate (1999), is provided below (the numbers represent the sonority index):

(1) Sonority scale

Vowels > Glides > Liquids > Nasals > Fricatives > Affricates > Stops

Vowels	Glides	Liquids	Nasals	Fricatives	Affricates	Stops
7	6	5	4	3	2	1

High sonority <--> Low sonority

As predicted by the SSP and the sonority hierarchy, onset clusters such as stop-liquid (e.g. /pl-/), where C1 is less sonorous than C2, are less marked in languages than onset clusters with a more sonorous C1, as liquid-stop (e.g. /lp-/) (Clements 1990, Yavas et al. 2008). Another principle related to the SSP is Sonority Distance, whereby clusters with larger sonority distance between the consonants are less marked than clusters with smaller sonority distance (Greenberg 1966, Clements 1990, Yavas et al. 2008).[2] A greater distance in sonority enhances the drop in sonority towards the edge of the syllable and follows the SSP more strictly. In addition, it enhances the dissimilarity between the consonants in the cluster and thus better facilitates perceptibility (Clements 1990, Cˆot´e 2000).

Another manifestation of contrast enhancement is the OCP, which prohibits adjacent identical elements, where "element" can refer to a segment or a feature (McCarthy 1986). This prohibition rules out homorganic clusters, consisting of consonants with the same place of articulation, and clusters with identical consonants.

Hebrew permits a wide variety of word initial consonant clusters, consisting mostly of two consonants (e.g. *gdud* 'battalion', *kfaʁ* 'village', *ʃlu'lit* 'puddle'). Word-final clusters are rare, occurring across morphemes in the 2nd feminine singular verb form (e.g. *ha'laxt* 'you fm.sg. walked', *a'vaʁt* 'you fm.sg. moved'), and within a morpheme in loan words (e.g. *bank* 'bank', *tost* 'toast'). Clusters of more than two consonants are also rare and usually occur in loan words (e.g. *ʃpʁic* 'squirt'). Adjacent consonants occurring word-medially are part of different syllables and are therefore not relevant here.

[2] The difference between the sonority index values of C1 and C2 represents the sonority distance of a particular cluster. For example, the sonority distance is 4 in a stop-liquid cluster and 2 in an affricate-nasal cluster.

Assuming the sonority hierarchy above, Hebrew allows SSP-violating clusters, and as in other languages, most of these clusters have an initial sibilant (*ʃki'a* 'sunset', *sti'ʁa* 'slap'). There are also other clusters which violate the SSP in substandard colloquial Hebrew (e.g. truncated imperatives as *ftax* 'open! ml. sg.', *xtov* 'write! ml. sg') (Bolozky 1979, Ben-David 2001, 2006, Bat-El 2002).

As for the sonority distance between the consonants, both obstruent-obstruent and obstruent-sonorant clusters occur in Hebrew. Sonorant-sonorant clusters, on the other hand, are quite rare and occur mainly when the first consonant is *m* and in loan words (Ben-David 2001, 2006, Schwarzwald 2005). Possible initial biconsonantal clusters are presented in (2) (a table of the consonants in Hebrew is presented in Appendix 1).

(2) Possible initial biconsonantal clusters in Hebrew

Cluster type	Example
obstruent-obstruent	
stop-stop	*pka'ot* 'corms'
stop-affricate	*p¢a'¢a* 'bomb'
stop-fricative	*kviʃ* 'road'; (sibilant:) *psan'teʁ* 'piano'
affricate-stop	*¢da'ka* 'charity'
affricate-fricative	*¢xok* 'laughter'
fricative-stop	*ftax* 'open!'*; (sibilant:) *ʃgia* 'error'
fricative(sibilant)-affricate	*'s¢ena* 'scene'**
fricative(sibilant)-fricative	*zxu'xit* 'glass'
fricative(sibilant)-fricative(sibilant)	*ʃzi'ʁa* 'interweaving'
obstruent-sonorant	
stop-nasal	*pnai* 'leisure'
stop-liquid	*kli* 'tool'
stop-glide	*tjo'ta* 'draft'
affricate-nasal	*¢mi'xa* 'growth'
affricate-liquid	*¢lo'fax* 'eel'
fricative-nasal	*xnun* 'nerd'**; (sibilant:) *sma'lim* 'symbols'
fricative-liquid	*vʁid* 'vein'; (sibilant:) *sʁox* 'shoelace'
fricative-glide	*fjord* 'fjord'**; (sibilant:) *sjag* 'restriction'
sonorant-sonorant	
nasal-liquid	*mlai* 'inventory'
nasal-glide	*njut'ʁon* 'neutron'**

*Very rare and only in substandard colloquial Hebrew; ** Very rare and only in loan words

Following the OCP, clusters with two labial consonants do not occur. Other clusters with homorganic consonants must differ in manner of articulation; e.g. *sla'im* 'rocks', *kxu'lim* 'blue m. pl.' (see Padgett 1995 regarding the existence of OCP-subsidiary features limiting root co-occurrence restrictions in coronals and dorsals; see also Schwarzwald 2005, Ben-David 2006).

Language specific restrictions on cluster formation in Hebrew include remnants of Biblical Hebrew post-vocalic spirantization, which prohibits the labial stops *p* and *b* from occurring at the second position of a cluster and the fricatives *f*, *v* and *x* from occurring as the first consonant. This restriction, as well as an historical prohibition on the appearance of a guttural as the first consonant in a cluster, leads to the scarcity of word-initial clusters beginning with a fricative (Ben-David 2001, 2006, Adam 2002, Schwarzwald 2005).

Many of the word-initial clusters in Hebrew are derived due to a vowel deletion process occurring with the addition of a suffix; e.g. *'sefeʁ – sfa'ʁim* 'book sg.–pl.', *ka'xol – kxu'lim* 'blue sg.–pl.', *ka'tan – kta'na* 'small fm.sg.–fm.pl.' (Bolozky 1991, Bat-El 2008). Derived clusters in verbs are found in truncated imperative forms, as in *ʃmoʁ* 'gourd! ms. sg.' (derived from the future form *tiʃ'moʁ*) (Bolozky 1979, Bat-El 2002).

1.2 The acquisition of consonant clusters

The acquisition of consonant clusters is relatively long in duration, and the process of development is gradual (McLeod et al. 2001, Ben-David 2001). Children apply different cluster simplification strategies at the stages where their grammar does not allow clusters. The most common strategy is **cluster reduction**, whereby only one of the target consonants in a cluster is produced (e.g. *bu* for *blu* 'blue' (English); *ka'vim* for *kla'vim* 'dogs' (Hebrew)) (Dyson and Paden 1983, Fikkert 1994, Gnanadesikan 1995/2004, Bernhardt and Stemberger 1998, Mcleod et al. 2001, 2001b, Ben-David 2001, Kappa 2002 and many others).

Within the Optimality Theory framework, cluster reduction is attributed to the ranking of the markedness constraint *COMPLEX, which does not allow more than one element in a sub-syllabic unit, above the faithfulness constraint MAX, which prohibits deletion (Pater and Barlow 2003, Gnanadesikan 1995/2004):

(3) Cluster reduction: *COMPLEX >> MAX

a. *COMPLEX Onsets and Codas are simple

b. MAX Input segments must have output correspondents (i.e. no deletion)

Assuming that the child's input is similar to the adult's surface form (i.e. the target word), as is commonly assumed in studies of language acquisition (e.g. Smolensky 1996a,b, Tesar and Smolensky 1998, Gnanadesikan 1995/2004), the deleted consonant in cluster reduction is an input segment which does not have a correspondent in the output. Therefore, MAX is violated when a cluster is reduced.

The selection of the realized segment has mostly been attributed to relative sonority (e.g. Fikkert 1994, Gnanadesikan 1995/2004, Bernhardt and Stemberger 1998, Ohala 1999, Barlow 2005). The universal preference for low sonority onsets predicts that reduction of onset clusters will result in the preservation of the less sonorous consonant, following the sonority hierarchy of consonants. In Optimality Theory, the relation between sonority level and onset position is represented in a scale of universally ranked sonority constraints (Adam 2002, Pater and Barlow 2003):

(4) Onset sonority hierarchy

*G-ONS >> *L-ONS >> *N-ONS >> *F-ONS >> *A-ONS >> *S-ONS

(Where G=Glide, L=Liquid, N=Nasal, F=Fricative, A=Affricate, S=Stop)

The highest ranked constraint in this scale prohibits onset glides[3], which are the most sonorous consonants, and the lowest ranked constraint prohibits onset stops, which are the least sonorous. The onset sonority hierarchy, then, leads to the realization of the less sonorous consonant of the adult target cluster when a cluster is reduced. For example, cluster reduction is expected to result in *kavim* for the target *klavim* 'dogs', since *k* is less sonorouse than *l* and thus a better onset.

However, not all reduction patterns follow the sonority hierarchy. For example, various studies of cluster acquisition report that *s*-clusters are usually reduced to the second consonant, regardless of the relative sonority level of the two segments (e.g.

[3] Clusters with glides are rare in Hebrew and almost never occur in child language (Ben-David 2006). Therefore, *G-ONS is not relevant to the current discussion and is ignored from now on.

ni:z for *sni:z* 'sneeze', *ton* for *ston* 'stone' (English); *la:p* for *sla:p* 'sleep', *tɛp* for *stɛp* 'scooter' (Dutch); *'naim* for *'ʃnaim* 'two ml.', *'taim* for *'ʃtaim* 'two fm.' (Hebrew)) (Fikkert 1994, Barlow 2001, Ben-David 2001, 2006, Pater and Barlow 2003, Yavas et al. 2008 among others). Different explanations have been offered in order to account for the deviation from the sonority scale (Ben-David 2001, Pater and Barlow 2003, Jongstra 2003, Goad and Rose 2004 and others). One such explanation is the requirement for contiguity between segments, which results in the deletion of the consonant closer to the edge of the syllable and the preservation of the consonant closer to nucleus (the vowel). Note that the consonant adjacent to the vowel is more salient perceptually than the marginal consonant, due to the sharp consonant-to-vowel transition (Steriade 1982, Ben-David 2001). The following faithfulness constraint represents this requirement:

(5) CONTIG Corresponding portions of the input and output form a contiguous string (i.e. no medial epenthesis or deletion of segments)

The ranking of CONTIG above one or more of the sonority constraints can result in the preservation of the more sonorous consonant in a cluster. For example, when CONTIG is ranked between *L-ONS and *N-ONS (6a), C1 is deleted, following CONTIG, unless C2 is a liquid. Thus, a sibilant-nasal cluster is reduced to nasal, but a sibilant-liquid cluster is reduced to sibilant. Similarly, when CONTIG is ranked between *N-ONS and *F-ONS (6b), C1 is deleted, following CONTIG, unless C2 is a liquid or a nasal. That is, a sibilant-fricative cluster is reduced to fricative, but a sibilant-nasal cluster is reduced to sibilant.

(6) CONTIG and *SEG-ONS constraints

a. $_{\omega}$[$C_1C_2V \rightarrow C_2V$, except when C_2 = liquid

*L-ONS>> **CONTIG** >>*N- ONS >>*F- ONS >>*A- ONS >>*S- ONS

b. $_{\omega}$[$C_1C_2V \rightarrow C_2V$, except when C_2 = liquid or nasal

*L-ONS>> *N- ONS >> **CONTIG** >> *F- ONS >>*A- ONS >>*S- ONS

Another strategy used by children to avoid the production of a cluster is **vowel epenthesis**, whereby a vowel is inserted between the cluster consonants (e.g. *bʌlu* for *blu* 'blue' (English); *gəvi'na* for *gvi'na* 'cheese' (Hebrew)). This strategy is reported in many studies to be limited and infrequent (e.g. Greenlee 1974, Chin and Dinnsen 1992, Fikkert 1994, Bernhardt and Stemberger 1998, Ben-David 2001), altough in the database of the present study this is not the case (see §5.2; cf. Freitas 2003).

Vowel epenthesis is enabled by the ranking of *COMPLEX above DEP, a faithfulness constraint forbidding epenthesis:

(7) DEP Output segments must have input correspondents (i.e. no epenthesis).

Epenthesis can also be attributed to other effects. In monosyllabic words, it may be related to the minimal word constraint (Fikkert 1994, Demuth and Fee 1995; see Taelman and Gillis 2008 for a different view), which restricts the prosodic words produced by children to a binary foot both minimally and maximally (Demuth 1995, Demuth and Fee 1995, Adam 2002). A binary foot in Hebrew is disyllabic, as the language is quantity insensitive and a moraic analysis of feet does not apply (Bolozky 1982, Bat-El 1994, 2005, Graf 1999), and the production of a disyllabic minimal word may lead to vowel insertion.

In derived words that do not have a cluster in their base (e.g. *gdo'la* 'big fm. sg.', where the base is *gadol*, *¢va'im* 'colors', where the base is *¢eva*), vowel epenthesis may occur due to paradigmatic effects requiring faithfulness to the base. In such cases, we can assume that the child's input is the base rather than the target word (i.e. the adult surface form) and the vowel is inserted in order to satisfy prosodic faithfulness between the target word and the base (cf. Adam and Bat-El 2008).

The constraints reflecting paradigm faithfulness and minimal word restrictions exceed the scope of this paper and are not discussed here. In any case, their possible influence does not exclude the role of *COMPLEX in insertions between the cluster consonants, because the vowel breaks the cluster into two separate syllables and prevents its production in the onset of a single syllable. It is likely that more than one force influences the child's productions, so that both the discussed effects and the desire to simplify syllable structure lead to the insertion of a vowel between the consonants.

Other simplification strategies include **coalescence** - the production of one consonant containing features of both original consonants (e.g. *fun* for *spun* 'spoon' (English); *pa'dea* for *¢faʁ'dea* 'frog' (Hebrew)) and **metathesis** - the reversal of segments (e.g. *giv'na* for *gvi'na* 'cheese' (Hebrew)). These strategies are also reported to be quite rare (e.g. Greenlee 1974, Dyson and Paden 1983, Bernhardt and Stemberger 1998, McLeod et al. 2001, Ben-David 2001).

Coalescence and metathesis are enabled by the low ranking of UNIFORMITY and LINEARITY, respectively:

(8)	UNIFORMITY	No element of the output has multiple correspondents in the input (i.e. no coalescence)
(9)	LINEARITY	The output reflects the precedence structure of the input, and vice versa (i.e. no metathesis)

The production of a non-target cluster in which one or both consonants are different than the target cluster is sometimes considered a cluster simplification strategy (e.g. Greenlee 1974, Watson and Scukanec 1997, McLeod et al. 2001, Kirk 2008). Smit (1993) found that almost all substitutions of the cluster consonants are predicted from the production of the corresponding singletons (through the application of simplification processes such as gliding, stopping, fronting and consonant harmony) and are therefore not specific to clusters. Kirk 2008, on the other hand, found that almost one third of the substitutions are unpredictable and that most of these are motivated by assimilation within the cluster, particularly place assimilation. In any case, since a consonant cluster *is* produced in such cases, and therefore *COMPLEX is violated, I do not discuss the constraints responsible for non-target clusters.

Another phenomenon reported in children's productions of target words with initial clusters is the deletion of the entire onset (e.g. *u* for *blu* 'blue' (English); *a'xim* for *pʁa'xim* 'flowers' (Hebrew)) (Greenlee 1974, McLeod et al. 2001, Freitas 2003, Ben-David 2001). This pattern is found also in productions of target words with simple onsets, and is not necessarily related to the avoidance of clusters (Ben-David 2001, Adi-Bensaid and Ben-David 2010; and see §5.7). The constraints motivating these deletions are therefore not presented here.

The different strategies are applied variably by children in the process of consonant cluster acquisition and many studies have suggested that they reflect different stages or sub-stages in that process (e.g. Greenlee 1974, Ingram 1976, Fikkert 1994, McLeod et al. 2001, Ben-David 2001, Freitas 2003). Ingram (1976) proposed four major stages of cluster development based on Greenlee's (1974) stages for the acquisition of stop-liquid clusters:

a. Stage 1: Deletion of the entire cluster.
b. Stage 2: Reduction of the cluster to one member (cluster reduction).
c. Stage 3: Use of a cluster with substitution for one of the members (non-target cluster).
d. Stage 4: Correct articulation.

The results of the current study suggest that the acquisition of consonant clusters is not comprised of such distinct stages, or more accurately, that the simplification strategies are multiple means to simplify cluster production rather than reflections of distinct stages of development. This point is discussed in detail in §5.11. The following section reviews previous studies on the acquisition of clusters in Hebrew.

1.3 The acquisition of consonant clusters in Hebrew: Previous studies

The findings of previous studies of cluster reduction in the acquisition of Hebrew consonant clusters are not consistent. Some studies suggest a tendency for the deletion of the second consonant in a cluster (C2) (Rosenberg 1983), while others revealed a preference for deletion of the first consonant (C1) (Lavie 1978, Forkush 1997). Ben David's (2001) longitudinal study of 10 children reported a tendency to delete C2 in obstruent-liquid clusters and C1 in all other types of clusters, including obstruent-nasal clusters. The deletion of a liquid in C2 position was attributed to its sonorous nature and to the compliance with the sonority hierarchy. The deletion of C1 was attributed to the preference of contiguity in all other cases. To mirror these tendencies in constraint ranking, CONTIG was ranked below *L-ONS, the constraint prohibiting onset liquids, and above all other sonority constraints (see (7a) and (11c)). Exceptions to these preferences were considered manifestations of different stages or sub-stages in the process of consonant cluster acquisition, resulting from changes in the ranking of constraints.

Ben-David (2001) found no significant difference between *s*-clusters and other clusters in Hebrew, since C1 was deleted in most cases whether it was a sibilant or not. Ben-David (2006) examined reduction patterns and accuracy rates in the acquisition of *s*-clusters in 40 typically developing children. Regarding reduction patterns, more deletions of C2 compared to C1 were found in clusters where C2 was a liquid and more deletion of C1 were found in the other *s*-clusters. In general, no significant differences were found between children's productions of *s*-clusters and productions of other clusters.

As for other simplification strategies, very few cases involving epenthesis, metathesis and coalescence were found in Ben-David (2001).

Ben-David (2001) proposed five stages in the acquisition of word-initial consonant clusters, which partially coincided with the stages proposed for the acquisition of simple onsets. These stages and their respective constraint rankings are presented below (only rankings relevant to the current discussion are brought here):

a. Deletion of the entire onset (CCV → V): This type of deletion was found in early productions of targets with word-initial complex onsets as well as word-initial simple onsets.

b. Production of an onset consonant identical to the onset of the following syllable ($C_1C_2VC_3V \rightarrow C_3VC_3V$): Like the deletion of the entire onset, the reduplication of the onset of the second syllable was found in early attempts at production of both clusters and simple onsets.

c. Production of one of the consonants in the target cluster - cluster reduction, coalescence (CCV → CV): Three phases of cluster reduction were found, expressed by the gradual promotion of CONTIG:

   i. Production of the less sonorous consonant: This phase was attributed to an earlier ranking of CONTIG below all the onset sonority constraints:

      *COMPLEX>>MAX, *L-ONS>>*N-ONS>>*F-ONS>>*S-ONS>>**CONTIG**

   ii. Production of C2, unless C2 is a liquid: As discussed above, the following ranking was suggested to account for this phase:

      *COMPLEX>>MAX, *L-ONS>>**CONTIG**>>*N-ONS>>*F-ONS>>*S- ONS

   iii. Production of C2 regardless of its relative sonority: This phase occurred close to the end of the single-consonant stage, and was explained by the ranking of CONTIG above all the onset sonority constraints:

      *COMPLEX>>MAX, **CONTIG** >>*L-ONS>>*N-ONS>>*F-ONS>>*S-ONS

   Altough there was evidence for only these three intermediate rankings, CONTIG was assumed to be gradually promoted above each of the sonority constraints.

   Cases involving coalescence occurred early in the process of cluster acquisition and were attributed to the ranking of IDENT, a faithfulness constraint requiring identity between the features of input and output segments, below the onset sonority constraints:

*COMPLEX>>MAX,*L-ONS>>*N-ONS>>*F-ONS>>*S-ONS>>CONTIG>>IDENT

d. Attempts to produce both cluster consonants - epenthesis, metathesis (CCV → CVC): Epenthesis and metathesis were thought to reflect a stage in the course of acquisition, occurring later than cluster reduction and closer to the beginning of adult production, in which both consonants are realized but separated into two syllables by vowel insertion or segment reversal.

   Epenthesis was attributed to the ranking of DEP below *COMPLEX and MAX:

   *COMPLEX, MAX>> IDENT-ONS, DEP, CONTIG, *SEG-ONS

   (IDENT-ONS requires identity between feature values of input and output onset segments).

   Metathesis was attributed to the following ranking:

   *COMPLEX, MAX, DEP>> LINEARITY>> *SEG-ONS

e. Correct production: At this stage *COMPLEX was ranked below the faithfulness constraints:

   MAX, IDENT-ONS, DEP, LINEARITY, CONTIG>>*COMPLEX, *SEG-ONS

Similar stages and reduction patterns were found in the speech of Hebrew acquiring hearing impaired children using cochlear implant (Adi-Bensaid 2006, Adi-Bensaid and Ben-David 2010). In Adi-Bensaid and Ben-David (2010), the general tendency to delete C1 was attributed to contiguity and the tendency to delete C2 in obstruent-liquid clusters was attributed to the markedness of the liquids.

2. Thesis objectives

The studies on the acquisition of Hebrew clusters reviewed above are limited with respect to the examination of cluster simplification strategies. Ben-David's (2001) study, although longitudinal, was qualitative and did not present quantitative results. The data were gathered through weekly language sampling of spontaneous speech and a specially devised test administered monthly. Ben-David (2006) is a cross-sectional quantitative study that focused on *s*-clusters.

A quantitative analysis of data attained in a longitudinal study (through weekly recordings), as in the present study, may give further insight into some questions arising in relation to the acquisition of consonant clusters. The issues addressed in this study are the following:

a. Patterns of cluster reduction: What are the roles of sonority and contiguity in the acquisition of clusters?

b. The comparison between *s*-clusters and other clusters: Do *s*-clusters have a special status, as reported in other languages (see §1.2)?

c. Variability: Does the variability in simplification strategies reflect distinct developmental stages?

3. Research method

3.1 Data source

The data in this study are drawn from a longitudinal study of two typically developing Hebrew-acquiring children, RM (age 1;3.13–2;11.28) and SR (age 1;02.00–2;04.03). The study is a part of Bat-El and Adam's Child Language Project at Tel Aviv University. The data were collected during weekly one-hour sessions in the child's natural environment. All data used here were obtained from spontaneous speech and picture/object naming.

3.2 Method of examination

3.2.1 Cluster types

In order to examine the patterns in the acquisition of clusters, the children's attempted targets containing word-initial clusters are examined based on cluster type. For this purpose, cluster types are defined as different combinations of manners of articulation of adjacent consonants. The following cluster types were found in the children's attempted targets:

(10) Cluster types[4]

Cluster type	RM	SR
stop-stop	gd, kt, pk, pt	gd, kt, pk
stop-*s*	k¢, ps	k¢, ks, ps
stop-fricative	dv, gv, kv, kx, tx	dv, gv, kf, kv, kx, tx
stop-nasal	dm, gm, km, kn, pn, tm	dm, km, tn
stop-liquid	bl, bʁ, dl, gl, kl, kʁ, pl, pʁ, tʁ	bl, bʁ, dʁ, gl, kl, kʁ, pʁ, tʁ
fricative-liquid	fl, vʁ, zʁ	fl
s-stop	¢d, sg, ʃp, ʃt, sp, st	ʃt, sk, sp
s-fricative	¢f, ¢v, sf, ʃf, ʃv, ʃx, sv, zv, zx	¢f, ¢v, zv
s-nasal	¢m, ʃm, ʃn, sm, sn	ʃm, ʃn, sn
s-liquid	¢ʁ, ʃl, ʃʁ	ʃl, ʃʁ, sl

Some cluster types were not attempted by the children: fricative-stop, sibilant-sibilant (affricate and fricative), C-glide, fricative-nasal and nasal-liquid. These are all rare clusters in Hebrew (see §1.1).

3.2.2 Categories of productions

Thirteen categories of productions were counted for each cluster type for the purpose of comparison between cluster types:

(11) Categories

a. C1 deletion

Productions in which C1 is deleted and C2 is realized; e.g. *ta'na* for *kta'na* 'small fm. sg.'

b. C2 deletion

Productions in which C2 is deleted and C1 is realized; e.g. *kum* for *klum* 'nothing'.

c. Epenthesis

[4] Clusters containing the affricate sibilant are combined with clusters containing fricative sibilants.

Productions in which a vowel is inserted between the cluster consonants; e.g. *gədo'la* for *gdo'la* 'big fm sg.'. This category includes cases in which the target cluster consonants are replaced with other consonants, such as *se'lita* for *'glida* 'ice cream' *teva'im* and *seba'ʔim* for *¢va'im* 'colors', *ʃi'buux* for *zvuv* 'fly'.

d. Metathesis

Productions in which C2 and the following vowel are reversed; e.g. *beʁ'xa* for *bʁe'xa* 'swimming pool'.

e. Coalescence

Productions in which the cluster is replaced with one consonant composed of features from both original consonants; e.g. *po'ʁa* for *dvo'ʁa* 'bee', where the manner feature (stop) is taken from the target C1 and the place feature (labial) from the target C2. Most cases in this category, including *po'ʁa*, can also be analyzed as the deletion of C1 and stopping of C2, but they are categorized here as coalescence.

f. Reduplication

Productions with an initial onset consonant identical to the onset of the following syllable; e.g. *va'vim* for *kla'vim* 'dogs'. This category also includes cases that can be analyzed in other ways. For example, *te'teea* for *¢far'dea* 'frog' can also be analyzed as the deletion of C2 and stopping of C1; *nə'noot* for *tmu'not* 'picures' can also be analyzed as coalescence.

g. Non-assimilatory substitution

Productions in which the cluster consonants are replaced with one consonant that is different from both consonants in the cluster and do not belong in any other category; e.g. *he'deja* for *¢far'dea* 'frog'.

h. Cluster deletion

Productions in which the entire cluster is deleted; e.g. *'ʔitθel* for *'ʃni¢el* 'schnitzel'.

i. Syllable deletion

Productions in which the first syllable is deleted; e.g. *vim* for *zvu'vim* 'flies'.

j. Filler syllable

Productions with an additional first syllable that breaks the cluster consonants into two separate syllables. In most of these cases a vowel is inserted at the beginning of the word, as in *akvi'na* for *gvi'na* 'cheese', but some cases involve an insertion of a CV syllable, as in *fiʃme'aa* for *¢me'a* 'thirsty fm. sg.'.

k. Multiple categories

Productions in which two of the above categories apply; e.g. in *ə'xi* for *kxi* 'you take fm.' C1 is deleted and a filler syllable is added.

l. Non-target cluster

Productions with an initial cluster that contains at least one consonant that is different than the target consonants. e.g *θbi* for *¢vi* 'gazelle', *'kʁaktoʁ* for *'tʁaktor* 'tractor', *'ʃteja* for *¢far'dea* 'frog'.

m. Correct production

Productions in which the cluster is faithful to the target cluster. A production of a cluster is regarded as correct when both consonants are produced correctly and no element is added or deleted before or after the cluster or between the consonants; e.g. *vʁu'dot* for *vʁu'dot* 'pink fm. pl.', *smo* for *smol* 'left'.

In the classification of productions, I ignored phonological phenomena that are not related to the production of the onset of the first syllable of the target word and phenomena that occur in singletons as well. These phenomena include:

a. Differences in voicing and vowel quality; e.g. *gnɛ'faim* for *kna'faim* 'wings' is considered correct, *va'ʁa* for *dvo'ʁa* 'bee' and *taf* for *¢daf* are classified as a C1 deletion.

b. For clusters containing a sibilant: the production of other sibilants or an interdental consonant instead of the target sibilant; e.g *ðvuv* for *zvuv* 'fly' is classified as correct, *'kuθteʁ* for *'skuteʁ* 'scooter' is classified as metathesis, *ʦə'mone* for *'ʃmone* 'eight' is classified as epenthesis.

c. The deletion of coda consonants, onsets of non-initial syllables and non-initial syllables; e.g. *pa* for *pkak* 'cork' is classified as C2 deletion, *ka'lim* for *kla'vim* 'dogs' is classified as metathesis, *'tɛ* for *kta'na* 'small fm. sg.' is classified as C1 deletion.

d. The insertion of non-initial syllables and coda consonants; e.g. *'sate* for *kʦat* 'a little bit' and *fu'dedeʁ* for *'sveder* 'sweater' are counted as C1 deletions, and *kenta'naa* for *kta'na* 'small fm. sg.' is classified as epenthesis.

e. The substitution of singletons in coda position or non-initial onset position; e.g. *de'vet* for *dvaʃ* 'honey' is counted as epenthesis, *ki'taa* for *kʦi'ʦa* is classified as C2 deletion.

f. The reversal of segments outside the cluster consonants; e.g. *saʁ'ten* for *psan'teʁ* 'piano' is classified as C1 deletion.

In each category, both the number of tokens and the number of types (per session) were counted for each recording session. The number of tokens is the total number of productions in a certain category. The number of types excludes productions of the same category for a particular target word occurring in one session. For example, the productions of *sva'im* and *ʦva'im* for *ʦva'im* 'colors' are counted as one type if they occur in the same session, as they are both considered correct productions of an *s*-fricative cluster, but they are counted as two tokens.

The distribution of productions (types and tokens) in each category was examined by cluster type (for each child) in order to evaluate the children's preferences in the application of simplification strategies. Where necessary, proportions were compared using chi-2 test.

3.2.3 Session groups

In order to compare simplification strategies based on gradual development, the data for each child are arbitrarily divided into 13 session groups. There are 4 sessions in each of SR's groups and 5 sessions in each of RM's groups (except for the first group of each child, which contains 7 sessions):

(12) Session groups for quantitative examination of gradual development

Period	**RM**	**SR**
1	1;03.27 – 1;05.10	1;02.00 – 1;03.14
2	1;05.14 – 1;06.12	1;03.19 – 1;04.10
3	1;06.19 – 1;07.24	1;04.17 – 1;05.08
4	1;08.01 – 1;09.10	1;05.15 – 1;06.02
5	1;09.18 – 1;10.28	1;06.12 – 1;07.02
6	1;11.18 – 2;00.16	1;07.09 – 1;08.03
7	2;00.30 – 2;01.27	1;08.10 – 1;09.00
8	2;02.04 – 2;03.01	1;09.09 – 1;09.27
9	2;03.14 – 2;04.12	1;10.07 – 1;11.07
10	2;04.19 – 2;05.27	1;11.16 – 2;00.05
11	2;05.29 – 2;06.29	2;00.21 – 2;01.11
12	2;08.24 – 2;09.29	2;01.25 – 2;02.17
13	2;10.03 – 2;11.28	2;02.22 – 2;04.03

These session groups allow a quantitative evaluation of the data on the basis of development and do not represent stages of development. They are used to detect development-based differences in each child's patterns of cluster simplification and not for a comparison between the children on that basis. RM's periods contain more sessions than SR's because her developmental pace is different than SR's. This difference is demonstrated in Bat-El's (2010) periods for the acquisition of verb inflectional suffixes (defined according to the number of cumulative target verbs attempted by the children), where RM's periods usually contain more sessions than SR's. Since the number of sessions is not evenly divided, the first group contains more sessions than the rest. The first group was selected to be the largest group because earlier sessions included very few attempts to produce target words with initial clusters, so there is less risk of influencing a development-based examination than in later periods.

4. Theoretical framework: Gradient constraint ranking

An Optimality Theoretic account represents stages in language acquisition as different rankings of constraints. These rankings are formed as a result of constraint reranking (by demotion or promotion), based on disparities between the child's output form and the adult's output form. The constraints are reranked until the target ranking is reached (Tesar and Smolensky 1993, 1998, Demuth 1995, 1997, Gnanadesikan 1995/2004, Bernhardt and Stemberger 1998 among others).

A common view regarding variability in children's productions is that the reranking of constraints creates variable intermediate stages in which some constraints are crucially unranked with respect to each other, so that more than one ranking is possible[5], allowing multiple optimal outputs for a single target word (see Demuth 1995, 1997, Bernhardt and Stemberger 1998, Adam 2002; see also Anttila 1997 regarding crucial non-ranking in adult language). This account implies a stage-by-stage reranking of constraints, where a change in the ranking of constraint pairs leads to different stages. An occurrence of different simplification strategies at different stages of development is a demonstration of such a reranking process, as suggested in Ben-David (2001) (see §1.3 above).

However, as I show below, a stage-by-stage reranking of constraints is not supported by the current data, as they reveal variable occurrence of multiple simplification strategies across time and production of adult clusters during a large part of the acquisition process (see §5.1.3 and §5.11). A model that can better account for these findings is a model of gradient constraint ranking and gradual learning, as suggested in Hayes (2000), Boersma (1997, 1998) and Boersma and Hayes (2001).

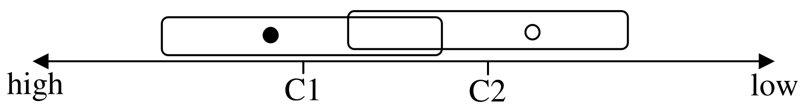
[5] Crucial non-ranking should not be confused with non-crucial ranking, whereby constraints are unranked with respect to each other due to the lack of evidence for their relative ranking.

This model adjusts the standard OT formalization of strict rankings between pairs of constraints and assumes a continuous ranking scale where higher values represent higher ranking. Whenever potential outputs are evaluated, the ranking values of constraints are temporarily modified by a small random amount (equal to all constraints) so that each constraint has a range of possible values. The value chosen for a particular constraint at a particular evaluation is called a selection point.

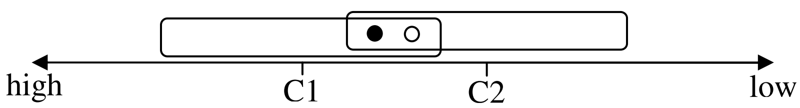
When constraints are close enough on the scale so that their ranges overlap, variation can occur, depending on the location of the selection points within the ranges. This is illustrated below (a black dot represents the selection point for C1 and a white dot represents the selection point for C2):

(13) Variable ranking

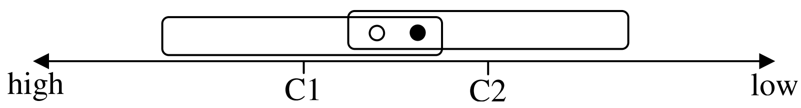
a. C1 >> C2



b. C1 >> C2



c. C2 >> C1

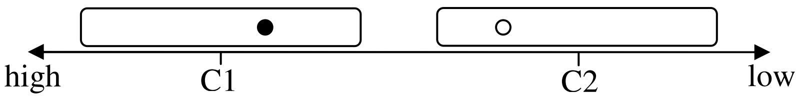


In (13a) and (13b), the selection point for C1 is higher on the scale than the selection point for C2 and therefore C1 outranks C2. In (13c), the selection point for C1 is lower than the selection point for C2, so that C1 is outranked by C2. Since the selection point can fall anywhere within the range, both rankings can occur, and the result is variation.

The selection points are normally distributed around the ranking value, so that the closer they are to it, the higher the probability that they are chosen. Therefore, the constraint with the higher ranking value will be ranked above the constraint with the lower ranking value in most evaluations. Depending on the distance between the ranking values of the constraints, the reverse ranking will sometimes occur.

When the ranges of constraint values do not overlap, the ranking is fixed, as illustrated in (14):

(14) Fixed ranking: C1 >> C2



The selection point for C1 in this case is always higher than the selection point for C2, and C1 always outranks C2.

The method by which candidates are evaluated at a particular evaluation time, whether it is based on constraint weights (as suggested, for example, in Pater, Potts and Bhatt 2007 and Pater 2008) or on conversion of numerical ranking values to ordered constraint rankings (as in Boersma and Hayes 2001), is not thoroughly explored here. For the purpose of simplifying the presentation, I adopt Boersma and Hayes's (2001) assumption that a strict ordered ranking is obtained at any evaluation, based on the selection points chosen at that time, and an Optimality Theoretic evaluation of outputs occurs. Accordingly, I use standard OT tableaux to present candidate evaluation for specific productions.

Boersma (1997, 1998) and Boersma and Hayes's (2001) model of learning, the Gradual Learning Algorithm (GLA), does not assume a change in the ranking order of constraint pairs. In this model, change is achieved through small incremental adjustments to constraint ranking values, which occur whenever a mismatch is detected between the child's form and the adult form. This way learning is gradual. I follow Boersma and Hayes in assuming gradual learning through moderate adjustments to the position of constraints along the scale. I also adopt their assumption that adjustments to constraint values occur in both directions: the values of constraints that are violated in the adult form are decreased, while the values of constraints that are violated in the child's form are increased. The exact mechanism of constraint value adjustment is not addressed here as it is not relevant for the issues at hand and the general assumptions of the model suffice.

The ranking of constraints in the initial grammar is assumed by many to reflect a dominance of markedness over faithfulness (Demuth 1995, Gnanadesikan 1995/2004, Smolensky 1996a,b, Levelt and Vijver 1998), leading to the preference for unmarked structures in early productions (Jakobson 1941/1968). In this study I assume that the markedness constraints *COMPLEX[6] and the sonority hierarchy are indeed strictly ranked above faithfulness constraints in the initial grammar. This assumption is supported by the fact that in the current data the children did not produce clusters, correct or otherwise, in their earliest attempts at producing target words with initial clusters (see §5.11) and by the fact that the earliest instances of cluster reduction are influenced by sonority alone (see §5.1.5).

In the following section I present the results of this study and analyze them assuming a gradient constraint ranking model as presented above.

5. Results and discussion

A quantitative comparison of simplification strategies and other non-adult productions is presented in the following table by cluster type. The percentage for each phenomenon is calculated out of the total number of productions for each cluster type. Since the results for types (per session) and tokens were essentially the same, the table specifies types only.[7]

[6] The correct production of the cluster consonants is affected by additional markedness constraints which motivate unfaithful productions of singletons as well (see discussion of non-target clusters below, §5.9), and these constraints must be demoted as well before all clusters are correctly produced. In the current discussion I ignore these constraints and focus on the ranking of *COMPLEX, as this constraint is the one motivating the application of the simplification strategies in focus.
[7] In the discussion below, numbers and percentages represent types per session, unless indicated otherwise.

(15) Non-adult productions

Cluster type	Child	Ttl	Correct		RDC	EPN	MT	CO	RDP	NS	OD	SD	FIL	MUL	NTC
stop-stop	RM	65	39	60%	**23%**	**15%**	0%	0%	0%	0%	0%	0%	**2%**	0%	0%
	SR	34	15	44%	**47%**	**3%**	**3%**	0%	0%	0%	**3%**	0%	0%	0%	0%
stop-*s*	RM	39	25	64%	**18%**	**3%**	0%	**3%**	0%	**3%**	0%	**3%**	0%	0%	**8%**
	SR	17	8	47%	**29%**	**18%**	0%	0%	0%	0%	0%	0%	0%	0%	**6%**
stop-fricative	RM	76	54	71%	**13%**	**7%**	0%	**3%**	0%	0%	0%	0%	**1%**	**3%**	**3%**
	SR	38	14	37%	**55%**	**8%**	0%	0%	0%	0%	0%	0%	0%	0%	0%
stop-nasal	RM	56	31	55%	**13%**	**20%**	**2%**	**2%**	**2%**	**2%**	0%	0%	0%	0%	**5%**
	SR	19	9	47%	**26%**	**26%**	0%	0%	0%	0%	0%	0%	0%	0%	0%
stop-liquid	RM	66	37	56%	**26%**	**6%**	0%	**3%**	0%	**2%**	**3%**	0%	0%	0%	**5%**
	SR	72	21	29%	**47%**	**6%**	**10%**	0%	**3%**	**1%**	**1%**	**3%**	0%	0%	0%
fricative-liquid	RM	7	2	29%	**43%**	0%	**29%**	0%	0%	0%	0%	0%	0%	0%	0%
	SR	2	1	50%	0%	0%	0%	0%	0%	0%	0%	**50%**	0%	0%	0%
s-stop	RM	40	20	50%	**38%**	**8%**	0%	0%	0%	0%	0%	0%	**5%**	0%	0%
	SR	23	5	22%	**52%**	**4%**	**4%**	0%	0%	0%	**13%**	0%	0%	0%	**4%**
s-fricative	RM	51	14	27%	**20%**	**25%**	**2%**	0%	**2%**	**4%**	**2%**	**8%**	**2%**	**2%**	**6%**
	SR	27	11	41%	**30%**	**11%**	0%	0%	0%	**4%**	0%	**4%**	0%	0%	**11%**
s-nasal	RM	50	29	58%	**14%**	**14%**	0%	0%	0%	0%	0%	0%	**6%**	**2%**	**6%**
	SR	22	10	45%	**41%**	0%	0%	0%	0%	0%	**14%**	0%	0%	0%	0%
s-liquid	RM	6	3	50%	**17%**	0%	**17%**	0%	0%	**17%**	0%	0%	0%	0%	0%
	SR	7	2	29%	**43%**	**14%**	0%	0%	0%	0%	**14%**	0%	0%	0%	0%
Total	RM	456	254	56%	**20%**	**12%**	**1%**	**1%**	**0.5%**	**1%**	**1%**	**1%**	**2%**	**1%**	**4%**
	SR	261	96	37%	**43%**	**8%**	**3%**	0%	**1%**	**1%**	**3%**	**2%**	0%	0%	**2%**

Total = total productions, Correct = faithful productions, RDC = reduction, EPN = epenthesis, MT = metathesis, CO = coalescence, RDP = reduplication, NAS = non-assimilatory substitution, OD = onset deletion, SD = syllable deletion, FIL = filler syllable, MUL= multiple categories, NTC = non-target cluster

As the above table shows, cluster reduction and epenthesis are the simplification strategies mostly employed by the children. I will examine the application of these strategies in §5.1 and §5.2. The other phenomena, some of which I do not consider to be cluster simplification strategies, were sparse. These phenomena will be discussed shortly in §5.3-§5.9. Variability in the application of simplification strategies, as it reflects gradual development, will be discussed in §5.11.

Another thing apparent in the above table is that the amount of data is quite small for a quantitative evaluation. For some cluster types, such as fricative-liquid and *s*-liquid, there are very few productions, making the evaluation very difficult. This is partially due to the scarcity of these clusters in adult language and the difficulty in their articulation. The correlation between the distribution of productions in the children's data and the distribution of cluster types in adult language is demonstrated in the comparison between the percentage of productions in the different cluster types and the percentage of Hebrew nouns containing these cluster types. The percentage of attempts for each cluster type, counting types per database (i.e. excluding productions of the same category for a particular target word, disregarding session), is presented in (16), from the largest to the smallest. These are compared with the distribution of cluster types in Bolozky and Becker's 2006 list of Hebrew nouns (LLHN), which consists of 12,043 nouns.

(16) Attempted cluster types cf. with cluster types in Hebrew

RM (total 174)		SR (total 141)		LLHN (total 923)	
stop-liquid	20%	stop-liquid	23%	stop-liquid	26%
stop-fricative	14%	stop-fricative	14%	stop-fricative	14%
s-nasal	14%	s-fricative	13%	*s*-fricative	11%
stop-stop	11%	stop-stop	12%	stop-stop	9%
s-fricative	10%	s-nasal	11%	*s*-stop	9%
s-stop	9%	s-stop	8%	stop-*s*	8%
stop-nasal	8%	stop-nasal	6%	*s*-liquid	8%
stop-*s*	5%	stop-s	6%	*s*-nasal	6%
s-liquid	4%	s-liquid	5%	stop-nasal	6%
fricative-liquid	4%	fricative-liquid	1%	fricative-liquid	2%

As can be seen from the table above, the rates of the children's attempted cluster types roughly correlate with that in the language, where stop-liquid and stop-fricative hold the highest rate and *s*-liquid and fricative-liquid hold the lowest rate.

For clusters with only a small number of productions it is difficult to determine simplification patterns and developmental effects. For example, RM had 8 productions (tokens) of *s*-liquid clusters. Two of these productions involved cluster reduction, where C2 was deleted in both. The two productions occurred in the same target word (*ʦʁi'xa* 'need fm. sg.') and within the same session. Based on these data, RM deleted 100% C2 in *s*-liquid clusters (counting either types per session or tokens), but it might not be enough in order to make a conclusive generalization and determine consistency in reduction. This should be taken into consideration when reviewing the data, and for that reason the actual number of productions is brought alongside the percentage in the discussion below. I begin with the discussion of cluster reduction.

5.1 Cluster reduction patterns

The percentage of C1 versus C2 deletions (types and tokens), calculated out of the total number of reductions for each cluster type, are provided in (17).

(17) C1 vs. C2 deletions

Cluster type	Child	Types					Tokens				
		Total	C1		C2		Total	C1		C2	
stop-stop	RM	15	12	**80%**	3	20%	22	18	**82%**	4	18%
	SR	16	12	**75%**	4	25%	20	16	**80%**	4	20%
stop-*s*	RM	7	4	**57%**	3	43%	7	4	**57%**	3	43%
	SR	5	5	**100%**	0	0%	7	7	**100%**	0	0%
stop-fricative	RM	10	7	**70%**	3	30%	12	9	**75%**	3	25%
	SR	21	9	43%	12	**57%**	30	11	37%	19	**63%**
stop-nasal	RM	7	3	43%	4	**57%**	8	3	38%	5	**63%**
	SR	5	2	40%	3	**60%**	8	4	50%	4	50%
stop-liquid	RM	17	2	12%	15	**88%**	22	2	9%	20	**91%**
	SR	34	1	3%	33	**97%**	100	1	1%	99	**99%**
fricative-liquid	RM	3	1	33%	2	**67%**	3	1	33%	2	**67%**
	SR	0	0	0%	0	0%	0	0	0%	0	0%
s-stop	RM	15	13	**87%**	2	13%	18	16	**89%**	2	11%
	SR	12	10	**83%**	2	17%	14	12	**86%**	2	14%
s-fricative	RM	10	1	10%	9	**90%**	12	1	8%	11	**92%**
	SR	8	8	**100%**	0	0%	11	11	**100%**	0	0%
s-nasal	RM	7	6	**86%**	1	14%	8	6	**75%**	2	25%
	SR	9	4	44%	5	**56%**	10	5	50%	5	50%
s-liquid	RM	1	0	0%	1	**100%**	2	0	0%	2	**100%**
	SR	3	1	33%	2	**67%**	7	4	**57%**	3	43%
Total	RM	92	49	**53%**	43	47%	114	60	**53%**	54	47%
	SR	113	52	46%	61	**54%**	207	71	34%	136	**66%**

There is a great deal of variability in the children's reductions, and this is most evident in the nearly equal proportion of total C1 and C2 deletions in the data of both children (RM 53%-47%, SR 46%-54%). Because of the limited amount of data, I do not accurately define consistent reduction patterns versus variable reduction patterns within individual cluster types, a definition that requires a minimum amount of productions for each cluster type. In the following discussion I compare reduction tendencies, and for that purpose I consider any percentage above 70 to indicate a clear tendency within a particular cluster type. I chose 70% because in most cases with a lower percentage, the actual numbers of the two types of deletions differ in only one production. Small tendencies, and of course even distributions, reflect bigger variability in the selection of the deleted consonant, and this aspect of the findings is discussed in §5.1.5.

As I show below in the discussion of the different cluster types, most of the children's reduction patterns can be explained on the basis of contiguity and relative sonority. Other effects, such as place of articulation and left edge anchoring, are also found, although to a much lesser extent. In order to compare the clusters based on reduction patterns, the tables in (18) present deletion tendencies on a scale of contiguity effect. The upper-most clusters, with a larger percentage of C1 deletion, show the strongest effect of contiguity, and the lower-most clusters, with a larger percentage of C2 deletion, show the weakest effect. The right column in each table specifies the sonority distance between the cluster consonants. The more sonorous consonant is specified in parentheses in the same row. Since affricates and fricatives have different sonority values, clusters containing the affricate sibilant are separated from clusters containing fricative sibilants in this presentation.[8] As there are no substantial differences between types (per session) and tokens, only types are specified in the tables and discussion below, unless otherwise indicated.

[8] In most cases, reduction trends are similar in clusters containing affricate sibilants and clusters containing fricative sibilants, but there are two possible exceptions in RM's data: in stop- affricate(*s*) RM had 2/5 (40%) C1 deletion versus 1/1 (100%) in stop-fricative(*s*), and in affricate(*s*)-fricative she had 0/9 (0%) C1 deletion versus 1/1 (100%) in fricative(*s*)-fricative clusters. Since these differences are based on a single production which constitutes 100% of the reductions in the relevant cluster types, I do not separate clusters containing affricates and clusters containing fricative-sibilants in the following discussion. However, I do consider the two types of consonants separately in the discussion of each *s*-cluster.

(18) Contiguity scale

RM		
Cluster type	C1 deletion	Sonority
fric(*s*)-fricative	100% (1/1)	0
affr(*s*)-stop	100% (2/2)	1 (C1)
stop-fric(*s*)	100% (1/1)	2 (C2)
affr(*s*)-nasal	100% (1/1)	2 (C2)
fric(*s*)-stop	86% (12/14)	2 (C1)
fric(*s*)-nasal	83% (5/6)	1 (C2)
stop-stop	80% (12/15)	0
stop-fricative	70% (7/10)	2 (C2)
stop-nasal	43% (3/7)	3 (C2)
stop- affr(*s*)	40% (2/5)	1 (C2)
fricative-liquid	33% (1/3)	2 (C2)
stop-liquid	12% (2/17)	4 (C2)
aff(*s*)-fricative	0% (0/9)	1 (C2)
affr(*s*)-liquid	0% (0/1)	3 (C2)

strong effect ↑ contiguity ↓ weak effect

SR		
Cluster type	C1 deletion	Sonority
fric(*s*)-fricative	100% (3/3)	0
affr(*s*)-fricative	100% (5/5)	1 (C2)
stop-affr(*s*)	100% (4/4)	1 (C2)
stop-fric(*s*)	100% (1/1)	2 (C2)
fric(*s*)-stop	83% (10/12)	2 (C1)
stop-stop	75% (12/16)	0
fric(*s*)-nasal	44% (4/9)	1 (C2)
stop-fricative	43% (9/21)	2 (C2)
stop-nasal	40% (2/5)	3 (C2)
fric(*s*)-liquid	33% (1/3)	2 (C2)
stop-liquid	3% (1/34)	4 (C2)

The highest percentage of C1 deletions is found in *s*-clusters, although the deletion patterns in these clusters are not consistent and some of them have a higher percentage of C2 deletions (see §5.1.2 below). The lowest percentage of C1 deletions is found in C-liquid clusters. Also, even though the percentage of C1 and C2 deletions are nearly even when all clusters are considered, when C-liquid clusters are taken out of the calculation, as their deletion may result from production complexity rather than relative sonority (Adi-Bensaid and Ben-David 2010), there is a general tendency to delete C1; RM 65%-35% (46-25), SR 66%-34% (50-26). This general tendency is similar to the findings in Ben-David (2001).

When deletion tendencies are organized on a scale of sonority distance, as in (19), some correlation is found between the sonority distance and the percentage of C1 deletion:

(19) Sonority distance scale

RM

Cluster type	C1 deletion	Sonority
fric(*s*)-fricative	100% (1/1)	0
stop-stop	80% (12/15)	0
affr(*s*)-stop	100% (2/2)	1 (C1)
fric(*s*)-nasal	83% (5/6)	1 (C2)
stop- affr(*s*)	40% (2/5)	1 (C2)
aff(*s*)-fricative	0% (0/9)	1 (C2)
stop-fric(*s*)	100% (1/1)	2 (C2)
affr(*s*)-nasal	100% (1/1)	2 (C2)
fric(*s*)-stop	86% (12/14)	2 (C1)
stop-fricative	70% (7/10)	2 (C2)
fricative-liquid	33% (1/3)	2 (C2)
stop-nasal	43% (3/7)	3 (C2)
affr(*s*)-liquid	0% (0/1)	3 (C2)
stop-liquid	12% (2/17)	4 (C2)

small ↑ sonotiy distance ↓ large

SR

Cluster type	C1 deletion	Sonority
fric(*s*)-fricative	100% (3/3)	0
stop-stop	75% (12/16)	0
affr(*s*)-fricative	100% (5/5)	1 (C2)
stop-affr(*s*)	100% (4/4)	1 (C2)
fric(*s*)-nasal	44% (4/9)	1 (C2)
stop-fric(*s*)	100% (1/1)	2 (C2)
fric(*s*)-stop	83% (10/12)	2 (C1)
stop-fricative	43% (9/21)	2 (C2)
fric(*s*)-liquid	33% (1/3)	2 (C2)
stop-nasal	40% (2/5)	3 (C2)
stop-liquid	3% (1/34)	4 (C2)

For both children, clusters with a large sonority distance (3-4) have a low percentage of C1 deletion and clusters with no sonority distance (0) have a high percentage of C1 deletion. The clusters in the middle of the scale, those with a sonority distance of 1 and 2, exhibit more variation between the two children.

A large sonority distance facilitates the distinction between the two consonants in the cluster and thus allows a sonority-based selection (cf. Jongstra 2003). When the distinction is less accessible, the effect of contiguity emerges. In clusters where C1 is more sonorous than C2, i.e. *s*-stop clusters, contiguity and sonority converge towards C1 deletion. In clusters where C2 is more sonorouse than C1, we would expect a negative correlation between the percentage of C1 deletion and the sonority distance, i.e. the higher the sonority distance, the lower the rate of C1 deletion. The above scale supports this notion to a certain extent, but the correlation is not linear. It would be interesting to explore this correlation further against a larger database.

In the following sections I discuss the deletion patterns in each of the clusters, beginning with obstruent-sonorant clusters, continuing with *s*-clusters and finishing with obstruent-obstruent clusters. In each section I present the constraints relevant for the deletions in a particular cluster. Variability between reduction patterns and its relation to development as expressed in the framework of gradient constraint ranking, is discussed in §5.1.5.

5.1.1 obstruent-sonorant clusters

5.1.1.1 stop-liquid

Both children deleted mostly C2 in stop-liquid clusters; RM 88% (15/17), SR 97% (33/34). The following table presents examples of deletions in this cluster type. The productions are presented for each child separately and are ordered by age:

(20) Reduction in stop-liquid clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	1;06.05	ta	'tʁaktoʁ	'tractor'	C2
	1;07.10	pa'xa	pʁa'xim	'flowers'	C2
	1;09.10, 1;10.28	kum	klum	'nothing'	C2
	2;01.06	'pasteʁ	'plasteʁ	'band-aid'	C2
	2;02.25	ki'paa	kli'pa	'peel'	C2
	2;03.01	pə'xa	bʁe'xa	swimming pool'	C2
	2;04.12	tu'faa	tʁu'fa	'medicine'	C2
	2;05.15	kiis	klips	'clip'	C2
	2;06.12	li	dli	'bucket'	C1
	2;06.12	'ʁaktor	'tʁaktor	'tractor'	C1
	2;10.17, 2;11.14	pasta'lina	plaste'lina	'plasticine'	C2
	2;11.14	bon'dini	blon'dini	'blond'	C2
SR	1;05.08	'dila	'glida	'ice cream'	C1
	1;06.12, 1;11.02, 2;00.21	'gida	'glida	'ice cream'	C2
	1;06.12 - 2;03.24	'taktor	'tʁaktor	'tractor'	C2
	1;07.07, 1;07.17, 1;09.12	pa'xim	pʁa'xim	'flowers'	C2
	1;07.17, 2;03.24	'taktoʁim	'tʁaktoʁim	'tractor'	C2
	1;09.09- 1;11.07	ka'vim	kla'vim	'dogs'	C2
	1;11.02	be'xaa	bʁe'xa	swimming pool'	C2
	2;02.02	bo'dini	blon'dini	'blond'	C2
	2;02.06	da'kon	dʁa'kon		C2

The children's tendency towards deletion of C2 in this cluster type and in other C-liquid clusters is similar to the trend found in Ben-David (2001). It supports a sonority based selection, as the preserved consonant is the least sonorous. The relevant rankings are *COMPLEX >> MAX for any deletion and *L-ONS >> CONTIG and *L-ONS >> *S-ONS for deletion of the more sonorous consonant in the cluster.

(21) *COMPLEX >> MAX; *L-ONS >> CONTIG; *L-ONS >> *S-ONS[9]

klum → kum 'nothing' (RM 1;10.28)

/klum/	*COMPLEX	MAX	*L-ONS	CONTIG	*S-ONS
a. klum	*!		*		*
b. um[10]		**!			
c. lum		*	*!		
b. ☞ kum		*		*	*

The deletion of a liquid C2 can also be attributed to the late acquisition of liquids in Hebrew (Ben-David 2001, Adi-Bensaid 2006, Adi-Bensaid and Ben-David 2010) as in other languages (e.g. Stoel 1973, Ingram 1989, Vihman 1996) which results from the complexity in their production. However, the role of sonority is evident in other clusters where C2 is more sonorous than C1. The total percentage of deletions in clusters with a more sonorous non-liquid C2 (i.e. stop-*s*, stop-fricative, stop-nasal, affricate-fricative and *s*-nasal) is even in RM's data (50%-50% (20-20)) and near even in SR's data (56%-44% (25-20)). The deletions of C2 in those clusters support the sonority account, which may include the cases where C2 is a liquid.

There were very few forms where C1 was deleted in stop-liquids cluster, suggesting a marginal ranking CONTIG >> *L-ONS:

(22) *COMPLEX >> MAX; CONTIG >> *L-ONS >> *S-ONS

t'ʁaktoʁ → 'ʁaktoʁ 'tractor' (RM 2;06.12)

/tʁaktoʁ/	*COMPLEX	MAX	CONTIG	*L-ONS	*S-ONS
a. 'tʁaktoʁ	*!			*	*
b. ☞'ʁaktoʁ		*		*	
c. 'taktoʁ		*	*!		*

[9] Crucial constraint rankings (for a particular evaluation) are presented as far as they can be determined, and the relevant rankings are separated with a semicolon. A particular constraint appears more than once (as does *L-ONS in 21) if its ranking with respect to different constraints is represented. In the tableaux, a broken line indicates that the ranking between a pair of constraints is undetermined. For space considerations, I specify the relevant sonority constraints only.

[10] The ranking of MAX above the sonority constraint violated by the optimal candidate is assumed from now on, and a candidate without an onset, which is ruled out as a result of this ranking, will not be displayed.

SR's deletion of C1 occurred in the target word '*glida* 'ice cream', where he also reversed the onsets and produced *'dila*. The preference for an initial stop onset at the expense of precedence faithfulness results from the conflict between additional constraints, a conflict that is not explored here. Nevertheless, CONTIG must still be ranked above *L-ONS at this particular evaluation in order for *'dila* to be produced rather than *'gida*.

The constraint rankings accounting for cluster reduction in stop-liquid clusters are summarized below:

(23) Constraint rankings for stop-liquid clusters

Deletion	Constraint rankings	RM	SR
C1	**CONTIG >> *L-ONS** >> *S-ONS	12%	3%
C2	***L-ONS >> CONTIG**, *L-ONS **>>** *S-ONS	88%	97%

5.1.1.2 fricative-liquid

In fricative-liquid clusters, RM deleted 67% C2 (2/3) and SR had no reductions. RM's deletions are brought in (24):

(24) RM’s reductions in fricative-liquid clusters

Age	Child's production	Target word	Gloss	Deleted consonant
2;03.24	vo'dim	vʁu'dim	'pink m. pl.'	C2
2;04.05	ʁu'da	vʁu'da	'pink fm. sg.'	C1
2;09.13	vu'daa	vʁu'da	'pink fm. sg.'	C2

As in stop-liquid clusters, C2 deletion is attributed to relative sonority and the ranking *L-ONS >> CONTIG, while C1 deletion is attributed to contiguity and the opposite ranking, i.e. CONTIG >> *L-ONS:

(25) Constraint rankings for fricative-liquid clusters

Deletion	Constraint rankings	RM
C1	**CONTIG >> *L-ONS** >> *F-ONS	33%
C2	***L-ONS >> CONTIG**, *L-ONS **>>** *F-ONS	67%

5.1.1.3 stop-nasal

Both RM and SR had a near even distribution of C1 and C2 deletion in stop-nasal clusters; RM 43%-57% (3-4), SR 40%-60% (2-3). An exhaustive list of forms is brought in (26):

(26) Reduction in stop-nasal clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	2;00.30	tu'not	tmu'not	'pictures'	C2
	2;02.04, 2;03.01, 2;10.03	mo	kmo	'like'	C1
	2;02.25, 2;04.05	ko	kmo	'like'	C2
	2;03.29	ka'ʃaim	kna'faim	'wings'	C2
SR	1;03.14, 1;03.19, 1;11.07	ti	tni	'you give fm.'	C2
	2;00.00	mi'θa	kmi'¢a	'ring finger'	C1
	2;03.24	muna	tmuna	'pictue'	C1

The deletion of the nasal complies with the sonority hierarchy, preferring the less sonorous stop in the onset. Although percentages indicate variation rather than consistent reduction pattern, these deletions provide further demonstration of the role of sonority in cluster reduction. The constraint ranking that reflects the sonority based selection is *N-ONS >> CONTIG:

(27) *COMPLEX>>MAX; *N-ONS >> CONTIG; *N-ONS >> *S-ONS

kmo → ko 'like' (RM 2;04.05)

/kmo/	*COMPLEX	MAX	*N-ONS	CONTIG	*S-ONS
a. kmo	*!		*		*
b. mo		*	*!		
c. ☞ ko		*		*	*

The deletion of the stop, as other deletions of a less sonorous C1, can be explained by the contiguity account and the ranking CONTIG >> *N-ONS:

(28) *COMPLEX>>MAX; CONTIG >> *N-ONS >> *S-ONS

kmo → mo 'like' (RM 2;02.04)

/kmo/	*COMPLEX	MAX	CONTIG	*N-ONS	*S-ONS
a. kmo	*!			*	*
b. ☞ mo		*		*	
c. ko		*	*!		*

In SR's data, C1 deletion only occurred in target words with the labial *m* as C2, and it is possible that the preservation of the labial motivates these deletions as well (see discussion of the effect of MAX-LABIAL in §5.1.3.1). RM, on the other hand, deleted both C1 and C2 in stop-*m* clusters.

The constraint rankings for cluster reduction in stop-nasal clusters are therefore:

(29) Constraint rankings for stop-nasal clusters

Deletion	Constraint rankings	RM	SR
C1	**CONTIG >> *N-ONS** >> *S-ONS	43%	40%
C2	***N-ONS >> CONTIG**; *N-ONS **>>** *S-ONS	57%	60%

5.1.2 *s*-clusters

As discussed above (§1.3), previous studies on the acquisition of Hebrew clusters showed no significant difference between sibilant-initial clusters (*s*C) and non sibilant-initial clusters (CC) (Ben-David 2001, 2006). In the current data some differences were found, but they are not consistent enough to make a conclusive distinction.

A comparison between *s*C clusters and CC clusters is presented below:

(30) sC vs. CC

	Cluster Type	Types Total	C1		C2		Tokens Total	C1		C2	
RM	*s*C (all)	33	20	**61%**	13	39%	40	23	58%	17	43%
	*s*C excluding *s*-liquid	32	20	**63%**	12	38%	38	23	61%	15	39%
	SSP violating *s*C	15	13	**87%**	2	13%	18	16	89%	2	11%
	SSP following *s*C	18	7	39%	11	**61%**	22	7	32%	15	68%
	SSP following *s*C excluding *s*-liquid	17	7	41%	10	**59%**	20	7	35%	13	65%
	CC	52	25	48%	27	**52%**	67	33	49%	34	51%
	CC excluding C-liquid	32	22	**69%**	10	31%	42	30	71%	12	29%
SR	*s*C (all)	32	23	**72%**	9	28%	42	32	76%	10	24%
	*s*C excluding *s*-liquid	29	22	**76%**	7	24%	35	28	80%	7	20%
	SSP violating *s*C	12	10	**83%**	2	17%	14	12	86%	2	14%
	SSP following *s*C	20	13	**65%**	7	35%	28	20	71%	8	29%
	SSP following *s*C excluding *s*-liquid	17	12	**71%**	5	29%	21	16	76%	5	24%
	CC	76	24	32%	52	**68%**	158	32	20%	126	80%
	CC excluding C-liquid	42	23	**55%**	19	45%	58	31	53%	27	47%

The first row presents the percentage of deletions in all *s*C clusters (*s*-stop, *s*-fricative, *s*-nasal and *s*-liquid) while the second row excludes *s*-liquid. The third and fourh rows distinguish between SSP violating clusters (*s*-stop) and SSP following clusters. The fifth row excludes *s*-liquid from the SSP-following clusters. The sixth row presents the percentage of deletions in non-*s*-clusters (stop-stop, stop-fricative, stop-nasal, stop-liquid and fricative-liquid) and the seventh row excludes C-liquid clusters.

SSP violating *s*C clusters (third row) reflect a clear preference for C1 deletion, as both sonority and contiguity converge in favor of a stop onset (C2). The comparison between CC clusters (sixth row) and all *s*C clusters (first row) indicates a numerical preference for C1 deletion in *s*C clusters in both children's data, although the difference is only statistically significant in SR's data (RM: p-value=0.28, SR: p-value=0.002). When comparing CC clusters and SSP-following *s*C clusters (fourth row), SR still has more C1 deletions than C2 deletions in the *s*C clusters, and this difference is also statistically significant (p-value=0.009). RM, on the other hand, has more C2 deletions in SSP-following *s*C clusters than in CC cluster, but this difference is not statistically significant (p-value=0.59). These comparisons suggest that SR prefers the deletion of C1 in *s*C clusters, while RM exhibits no such preference.

SR's preference becomes less significant when liquid-final clusters are taken out of the comparison: he has a tendency to delete C1 in all three groups - *s*C clusters, SSP-following *s*C clusters and CC clusters (second, fifth and seventh rows, respectively), and although the percentage of C1 deletion is smaller in CC clusters, the difference is not statistically significant in the comparison with SSP-following *s*C clusters (p-value=0.69) and its significance is border-line in the comparison with *s*C clusters (p-value=0.07). A similar comparison in RM's case is even more interesting, as she has a tendency to delete C1 in CC (excluding C-liquid) clusters and an opposite tendency to delete C2 in SSP-following *s*C (excluding *s*-liquid) clusters. This difference, however, is not statistically significant (p-value=0.15).

To summarize, RM’s productions of target *s*C clusters follow Ben-David’s (2001, 2006) claim that these clusters are not different from other clusters. SR’s productions, however, suggest a possible distinction between these two types of clusters.

In the following sections I examine the individual cluster types containing a sibilant and compare them with stop-initial clusters. I do not conduct a formal statistical test for these comparisons, as the limited sample size makes such a test inappropriate.

5.1.2.1 *s*-stop

A large percentage of C1 deletions were found in *s*-stop clusters; RM 87% (13/15), SR 83% (10/12), similar to the tendency in stop-stop clusters (se**e** §5.1.3.1). Examples are brought in (31):

(31) Reduction in *s*-stop clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	1;11.25	taf	¢daf	'sea shell'	C1
	1;09.27-2;09.29	'taim	'ʃtaim	'two fm.'	C1
	2;01.16	'tai	'ʃtaim	'two fm.'	C1
	2;02.11	gu'lim	sgu'lim	'purple ms. pl. '	C1
	2;02.24	'tam	'ʃtaim	'two fm.'	C1
	2;03.01	θe'ʔe	ʃtey	'two of fm.'	C2
	2;04.19	sam	stam	'purposelessly'	C2
	2;04.19	taj	stam	'purposelessly'	C1
	2;06.29	'ta	'ʃtaim	'two fm.'	C1
SR	1;06.20-2;04.03	'taim	'ʃtaim	'two'	C2
	1;07.17	ki	ski	'ski'	C1
	1;09.12	pa'geti	spa'geti	'spaghetti'	C1
	2;00.05, 2;03.24	'θaim	'ʃtaim	'two'	C2

In these clusters, the initial sibilant, whether it is an affricate (in one example) or a fricative, is more sonorous than the second consonant and its deletion complies with the sonority hierarchy (see Ben-David 2001, 2006) as well as with the requirement for contiguity. Therefore, the rankings CONTIG >> *S-ONS and *F-ONS >> *S-ONS both motivate the deletion of C1:

(32) *COMPLEX>> MAX; CONTIG >> *S-ONS; *F-ONS >> *S-ONS

'ʃtaim→ 'taim 'ski' (SR 1;09.00)

/ʃtaim/	*COMPLEX	MAX	CONTIG	*F-ONS	*S-ONS
a. 'ʃtaim	*!			*	*
b. 'ʃaim		*	*!	*	
c. ☞ 'taim		*			*

As for the few cases in which C2 was deleted, they cannot be influenced by place of articulation, since the clusters consist of two coronals. It is possible that the preservation of the edge is at the root of these deletions, reflected by the high ranking of ANCHOR-L:

(33) ANCHOR-L A segment at the left edge of the input has a correspondent at the left edge of the output; i.e. no deletion or epenthesis at the left edge.

When ANCHOR-L is ranked above CONTIG, C2 is deleted:

(34) *COMPLEX>> MAX; ANCHOR-L >> CONTIG; ANCHOR-L >> *F-ONS >> *S-ONS

'ʃtaim→ 'θaim 'purposelessly' (SR 2;00.05)

/ʃtaim/	*COMPLEX	MAX	ANCHOR-L	CONTIG	*F-ONS	*S-ONS
a. *'ʃtaim*	*!				*	*
b. 'taim		*	*!			*
c. ☞ 'θaim		*		*	*	

Altough the interaction between ANCHOR-L and CONTIG would explain all the deletion patterns, as the dominance of ANCHOR-L leads to C2 deletion and the dominance of CONTIG leads to C1 deletion, such an account is inappropriate. If ANCHOR-L was motivating all C2 deletions, the percentage of C1 versus C2 deletion would be even and unaffected by segmental quality. However, a major part of the deletions of C2 can be explained on the basis of relative sonority. Therefore, the sonority account is more probable than the one based on prosodic edge preservation.

The following table summarizes the constraint rankings for *s*-stop clusters:

(35) Constraint rankings for *s*-stop clusters

Deletion	Constraint rankings	RM	SR
C1	CONTIG >> *S-ONS; *F-ONS >> *A-ONS >> *S-ONS; **CONTIG >> ANCHOR-L**	87%	83%
C2	**ANCHOR-L >> CONTIG**; ANCHOR-L >> *F-ONS >> *A-ONS	13%	17%

5.1.2.2 *s*-fricative

In *s*-fricative clusters, the children showed opposite tendencies, as RM deleted mostly C2 (90%, 9/10) and SR deleted only C1 (100%, 8/8). These are exemplified below:

(36) Reduction in *s*-fricative clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	2;00.30	¢e'deja	¢faʁ'dea	'frog'	C2
	2;00.30, 2;01.12	se'deja	¢faʁ'dea	'frog'	C2
	2;02.11	ze'im	¢va'im	'colors'	C2
	2;04.25	ʃaʁ'deja	¢faʁ'dea	'frog'	C2
	2;06.12	fu'dedeʁ	'svedeʁ	'sweater'	C1
	2;10.17, 2;11.14	¢aʁ'deeja	¢faʁ'dea	'frog'	C2
	2;11.03	saʁ'deaa	¢faʁ'dea	'frog'	C2
SR	1;05.15, 1;10.26	vi	¢vi	'gazelle'	C1
	1;07.09; 1;07.23, 1;08.03	vuv	zvuv	'fly'	C1
	1;10.26, 2;02.02	va'ʔim	¢va'im	'colors'	C1
	2;00.05	fa'dea	¢faʁ'dea	'frog'	C1

All of RM's C2 deletions occurred in clusters beginning with an affricate sibilant (*¢faʁ'dea* 'frog', *¢va'im* 'colors') and her one C1 deletion occurred in a cluster beginning with a fricative sibilant (*'svedeʁ* 'sweater'). The sonority account, i.e. the dominance of *F-ONS over *A-ONS and CONTIG, cannot explain RM's reductions in the affricate-fricative clusters, because in most of them she replaced the affricate sibilant with a fricative sibilant (7/11 tokens). Moreover, in stop-fricative clusters, which have a larger distance in sonority than affricate-fricative clusters, RM deleted the less sonorous C1 in most cases (70%, 7/10) (see §5.1.3.2). The production of a fricative sibilant instead of the affricate also rules out an explanation based on the avoidance of fricatives (Pater and Barlow 2003). These deletions may be affected by the desire to preserve the left edge, as suggested above in the discussion of C2 deletions in *s*-stop clusters. This is reflected by the ranking ANCHOR-L >> CONTIG:

(37) *COMPLEX >> MAX; ANCHOR-L >> CONTIG; *F-ONS >> *A-ONS

¢faʁ'dea → saʁ'deaa 'frog' (RM 2;04.19)

/¢faʁdea/	*COMPLEX	MAX	ANCHOR-L	CONTIG	*F-ONS	*A-ONS
a. ¢faʁ'dea	*!				*	*
b. faʁ'dea		*	*!		*	
c.☞ saʁ'deaa		*		*	*	

The reverse ranking CONTIG >> ANCHOR-L can explain the deletions of C1. In cases where C1 is an affricate, CONTIG must also dominate *F-ONS in order for the affricate to be deleted.

(38) *COMPLEX >> MAX; CONTIG >> ANCHOR-L; CONTIG >> *F-ONS >> *A-ONS

¢faʁ'dea → fa'dea 'frog' (SR 2;00.05)

/¢faʁdea/	*COMPLEX	MAX	CONTIG	ANCHOR-L	*F-ONS	*A-ONS
a. ¢faʁ'dea	*!				*	*
b. ☞ fa'dea		*		*	*	
c. ¢aʁ'dea		*	*!			*

Notice that RM's deletions of C2 occurred in coronal-labial clusters (¢f, ¢v), and the markedness hierarchy for place of articulation, which prefers coronals over labials and dorsals (Lombardi 1995), may also affect them. However, the effect of *LABIAL, although predictable by factorial typology, is usually not attested in cluster reduction (Pater and Barlow 2003).

SR deleted only C1 in both types of clusters: those beginning with an affricate sibilant and those beginning with a fricative sibilant, and the high ranking of CONTIG can account for his deletions. His deletion pattern in *s*-fricative clusters differs from his pattern in stop-fricative clusters, where he exhibited a small tendency to delete C2 (57%, 12/21) (see §5.1.3.2).

SR's tendency to delete the sibilant may be strengthened by his difficulty to produce this type of consonant, which is also found in singletons (e.g. in *a'pa* for *sa'pa* 'couch' (1;08.10) and *ʔi'naim* for *ʃi'naim* 'teeth' (1;11.22) SR deleted the initial sibilant, while at the same ages he produced the initial fricative *v* in *va'ʁod* for *va'ʁod* 'pink'). This difficulty is reflected not only in the deletion of sibilants, but also in their replacement with the interdentals *θ* and *ð* (which are not part of the Hebrew consonant inventory), in both singletons and clusters (e.g. *'ðaxal* for *'zaxal* 'caterpillar' (1;11.07), *θa'gol* for *sa'gol* 'purple' (2;02.02), *θna'i* for *sna'i* 'squirrel' (2;02.02); also, in SR's reductions of *s*-clusters, in all cases where he deleted the non-sibilant, he produced an interdetal instead of the sibilant). However, in *s*-nasal, *s*-liquid and stop-*s* clusters, SR did not show a tendency to delete the sibilant (se**e** §5.1.2.3, §5.1.2.4 and §5.1.2.5), so the influence of production complexity on his deletion of sibilants in clusters is not clear. Therefore, the constraints reflecting this influence are not discussed here.

The constraint rankings relevant for cluster reduction in *s*-fricative clusters are summarized below:

(39) Constraint rankings for *s*-fricative clusters

Deletion	Constraint rankings	RM	SR
C1	**CONTIG >> ANCHOR-L**; **CONTIG >> *F-ONS >> *A-ONS**	10%	100%
C2	**ANCHOR-L >> CONTIG**	90%	0%

5.1.2.3 *s*-nasal

In *s*-nasal clusters, RM deleted mostly C1 (86%, 6/7) and SR had a near even distribution of deletions (44%-56%, 4-5). Examples are given below:

(40) Reduction in *s*-nasal clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	2;00.16	mi'xa	smi'xa	'blanket'	C1
	2;01.12	se	ʃney	'two'	C2
	2;01.27, 2;11.14	ne	ʃney	'two'	C1
	2;01.27, 2;04.05	'naim	'ʃnaim	'two'	C1
	2;04.05	me'ʔaa	ȼme'a	'thirsty fm.'	C1
SR	1;06.20	'mone	'ʃmone	'eight'	C1
	1;07.09	na'ii	sna'i	'squirrel m.'	C1
	1;09.19	θe'em	ʃneyhem	'the two of them'	C2
	1;09.19	'nitθel	'ʃniȼel	'schnizel'	C1
	1;11.16	θa'ʔit	sna'it	'squirrel fm.'	C2
	1;11.22, 2;00.00 2;00.05	θa'taim	ʃna'tayim	'two years'	C2
	2;00.00	'naim	'ʃnaim	'two m.'	C1

As in stop-nasal clusters, the deletion of the nasal C2 supports a sonority-based selection and is attributed to the ranking *N-ONS >> CONTIG. The deletion of C1, a fricative in most cases and an affricate in only one case, supports a contiguity-based selection and results from the ranking CONTIG >> *N-ONS:

(41) Constraint rankings for *s*-nasal clusters

Deletion	Constraint rankings	RM	SR
C1	**CONTIG >> *N-ONS** >> *F-ONS >> *A-ONS	86%	44%
C2	***N-ONS >> CONTIG**; *N-ONS **>>** *F-ONS >> *A-ONS	14%	56%

The distribution of SR's deletions in *s*-nasal and stop-nasal clusters (see §5.1.1.3) was similar (approximately 40% C1 deletion for both), showing no indication for a difference between the two types of clusters. In RM's data, on the other hand, there was some difference, as she preferred C1 deletion in *s*-nasal clusters and showed no clear preference in stop-nasal clusters (43%-57%).

5.1.2.4 *s*-liquid

There were only a few attempted targets in *s*-liquid clusters, and only 4 reductions, all brought in (42). Most of these involved the deletion of C2; RM 100% (1/1), SR 67% (2/3).

(42) Reduction in *s*-liquid clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	2;03.01	¢i'xa	¢ʁi'xa	'need fm.'	C2
SR	1;06.02	lu'lit	ʃlu'lit	'puddle'	C1
	1;08.24	θimpθ	ʃʁimps	'shrimps'	C2
	2;04.03	ðafʁa'fon	ʃʁafʁa'fon	'stool'	C2

The deletion of C2, as in C-liquid clusters, complies with the sonority hierarchy and the ranking *L-ONS >> CONTIG, and the deletion of C1 complies with the ranking CONTIG >> *L-ONS:

(43) Constraint rankings for *s*-liquid clusters

Deletion	Constraint rankings	RM	SR
C1	**CONTIG >> *L-ONS** >> *F-ONS >> *A-ONS	0%	33%
C2	***L-ONS >> CONTIG**; *L-ONS **>>** *F-ONS >> *A-ONS	100%	67%

Here too, SR's deletion of the ʃ over the l in *ʃlu'lit* 'puddle' can also result from his avoidance of sibilants. It is also possible that this deletion results from the identity of the retained consonant (l) to the onset of the following consonant and from the acquisition of l before ʁ, due to articulatory differences between these two consonants (Ben-David 2001).

C2 is mostly deleted in stop-liquid and fricative-liquid clusters as well (see §5.1.1.1 and §5.1.1.2), although we need to keep in mind that the number of productions in *s*-liquid and fricative-liquid clusters is extremely small, making the comparison difficult.

5.1.2.5 stop-*s*

RM had a near even distribution of C1-C2 deletions in stop-*s* clusters (57%-43%, 4-3) and SR deleted only C1 (100%, 5/5). The following are examples of reductions in this cluster type:

(44) Reduction in stop-*s* clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	1;10.28	ki'taa	k¢i'¢a	'meatball'	C2
	2;01.19, 2;02.11	kat	k¢at	'a little'	C2
	2;01.19	*'sate*	k¢at	'a little'	C1
	2;05.29	saʁ'ten	psanteʁ	'piano'	C1
	2;11.14	¢at	k¢at	'a little'	C1
SR	1;09.09, 2;02.27	tθat[11]	k¢at	'a little'	C1
	2;01.11, 2;02.22	θat	k¢at	'a little'	C1
	2;03.24	θante'ʁim	psante'ʁim	'pianos'	C1

The deletion of C1 in these clusters reflects the ranking CONTIG >> *F-ONS or CONTIG >> *A-ONS, depending on the sibilant's manner of articulation. CONTIG must also outrank ANCHOR-L in order for C1 to be deleted:

(45) *COMPLEX>> MAX; CONTIG >> ANCHOR-L; CONTIG >> *A-ONS >> *S-ONS

k¢at → ¢at 'a little' (RM 2;01.19)

/k¢at/	*COMPLEX	MAX	CONTIG	ANCHOR-L	*A-ONS	*S-ONS
a. k¢at	*!				*	*
b. *kat*		*	*!			*
c. ☞ ¢at		*		*	*	

RM's deletions of C2 reflect the reverse ranking:

[11] *tθ* is treated as a single consonant, as it appears to replace ¢ in other productions, including faithful productions; e.g. *tθva'im* for *¢va'im* 'colors', *tθfaʁ'dea* for *¢faʁ'dea* 'frog' ,*tθvi* and *tθe'vi* for ¢vi 'gazelle'.

(46) *COMPLEX>> MAX; ANCHOR-L >> CONTIG; *A-ONS >> CONTIG ; *A-ONS >> *S-ONS

k¢at→ kat 'a little' (RM 2;01.19)

/k¢at/	*COMPLEX	MAX	ANCHOR-L	*A-ONS	CONTIG	*S-ONS
a. k¢at	*!			*		*
b. ☞ *kat*		*			*	*
c. ¢at		*	*!	*		

These C2 deletions occurred in stop-affricate clusters only, and the late acquisition of affricates (Ben-David 2001) is a possible explanation for them. However, affricates are not consistently deleted from clusters by RM. She deleted C2 in affricate-fricative (9/9) and affricate-liquid (1/1) clusters while deleting the affricate in affricate-nasal (1/1) and affricate-stop (1/1) clusters. This implies that it was not the affricate nature of the consonant that influenced RM's deletions of C2. It is also interesting to notice that although SR deleted the non-sibilant in all his reductions of stop-*s*, he replaced the sibilant with an inderdental consonant (see discussion of SR's avoidance of sibilants in §5.1.2.2).

Comparing stop-*s* clusters containing a fricative sibilant with stop-fricative clusters (see §5.1.3.2), the sibilants are not deleted more than the non-sibilant fricatives: RM deleted only C1 in stop-*s*(fricative) (100%, 2/2) and mostly C1 in stop-fricative (70%, 7/10); SR deleted only C1 in stop-*s*(fricative) clusters (100%, 1/1) and had a very small tendency towards C2 deletion on stop-fricative clusters (57%, 12/21).

The following table summarized the constraint rankings for cluster reduction in stop-*s* clusters:

(47) Constraint rankings for stop-*s* clusters

Deletion	Constraint rankings	RM	SR
C1	**CONTIG >> *F-ONS >> *A-ONS** >> *S-ONS	57%	100%
C2	***F-ONS >> *A-ONS >> CONTIG**; *F-ONS >> *A-ONS >> *S-ONS	43%	0%

To summarize, there are some differences between *s*-clusters and non-*s*-clusters in the children's data, more so in SR's, which may indicate a stronger competition for sonority when the first consonant is a sibilant. These differences are not consistent, though, and do not reveal any clear pattern that distinguishes sibilants from other consonants. It is very likely that they result from the smaller sonority gap in *s*-clusters compared with stop-initial clusters, which leads to the smaller distribution of a sonority based selection and therefore to more deletions of C1. In SR's case, it is also possible that they result from his tendency not to produce sibilants. Also, there are other deletion tendencies that deviate from the sonority pattern, such as the deletion of the first consonant in stop-fricative clusters, and these mask the importance of this distinction.

5.1.3 obstruent-obstruent clusters

In general, there was a tendency to delete C1 in obstruent-obstruent clusters, including *s*-clusters (i.e. stop-stop, stop-fricative, stop-*s, s*-stop, *s*-fricative): RM deleted 65% C1 (37/57) and SR deleted 71% C1 (44/62).

5.1.3.1 stop-stop

In clusters consisting of two stops, there was a tendency to delete C1 in both children's data; RM 80% (12/16), SR 75% (12/15). The table below presents examples of deletions in this cluster type:

(48) Reduction in stop-stop clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	1;10.13-2;04.19	ta'na	kta'na	'small fm. sg.'	C1
	1;10.13-2;04.19	ka'ja	kta'na	'small fm. sg.'	C1
	2;00.16	ke'naa	kta'na	'small fm. sg.'	C2
	2;00.30, 2;02.11, 2;09.13	do'la	gdo'la	'big fm. sg.'	C1
	2;00.30	do'lim	gdo'lim	'big m. pl.'	C1
	2;06.06	do'lot	gdo'lot	'big fm. pl.'	C1
SR	1;05.29, 1;09.09	pak	pkak	'cork'	C2
	1;07.09-2;04.03	ta'naa	kta'na	'small fm. sg.'	C1
	1;07.17, 2;02.06	do'la	gdo'la	'big fm. sg.'	C1
	1;08.03, 1;10.07	ka'na	kta'na	'small fm. sg.'	
	1;07.17	kak	pkak	'cork'	C1
	1;10.07	do'lim	gdo'lim	'big m. pl.'	C1
	2;00.00, 2;02.02	ta'nim	kta'nim	'small m. pl.'	C1
	2;00.21	ta'not	kta'not	'small fm. pl.'	C1
	2;01.06	do'lot	gdo'lot	'big fm. pl.'	C1

The high ranking of CONTIG can account for the deletions of C1. As for the deletions of C2, since the consonants are ranked equally on the sonority scale, the sonority constraints are not relevant in the selection. These deletions occurred in the words *pkak* 'cork' and *kta'na* 'small fm. sg.'. The preservation of the labial *p* in *pkak* can be an effect of MAX-LABIAL (see Pater and Barlow 2003 for the use of this constraint in sonority-defying reductions and other labial-preserving phenomena):

(49) MAX-LABIAL An input labial segment must correspond to an output labial.

This constraint is part of the MAX-PLACE hierarchy:

(50) MAX-DORSAL, MAX-LABIAL >> MAX-CORONAL

There is no agreement in the literature regarding the ranking between the dorsal faithfulness constraint and the labial faithfulness constraint (e.g. Gnanadesikan 1995/2004 proposes a universal dominance of IDENT-LABIAL over IDENT-DORSAL while Jun 1995 suggests the dominance of PRESERVE(PLACE(DORSAL)) over PRESERVE(PLACE(LABIAL))), and there might not be a universally fixed ranking between them (Pater 1997, de Lacy 2002). In this case MAX-LABIAL must dominate MAX-DORSAL in order for the labial to be preserved over the dorsal. The dominance of MAX-LABIAL over MAX-DORSAL and CONTIG results in the deletion of the non-labial C2. The ranking ANCHOR-L >> CONTIG is also necessary for this deletion to take place:

(51) *COMPLEX>> MAX-LABIAL >> MAX-DORSAL >> MAX; ANCHOR-L >> CONTIG; ANCHOR-L >> *S-ONS

pkak → *pak* 'cork' (SR 1;09.09)

/pkak/	*COMPLEX	MAX-LABIAL	MAX-DORSAL	MAX	ANCHOR-L	CONTIG	*S-ONS
a. pkak	*!						**
b. kak		*!		*	*		*
c.☞ pak			*	*		*	*

The children's deletions of the coronal C2 in *kta'na* can also be an effect of the above hierarchy, preferring the preservation of the dorsal over the coronal (see Pater 1997 for the effect of dorsal faithfulness in onset selection in truncation), as well as the high ranking of ANCHOR-L:

(52) *COMPLEX>> MAX-DORSAL >> MAX-CORONAL >> MAX; ANCHOR-L >> CONTIG

kta'na → ka'na (SR 1;08.03)

/ktana/	*COMPLEX	MAX-DORSAL	MAX-CORONAL	MAX	ANCHOR-L	CONTIG
a. ktana	*!					
b. tana		*!		*	*	
c. ☞kana			*	*		*

The constraint rankings for cluster reduction in stop-stop clusters are therefore:

(53) Constraint rankings for stop-stop clusters

Deletion	Constraint rankings	RM	SR
C1	**CONTIG >> MAX-LABIAL**; **CONTIG >> ANCHOR-L**	80%	75%
C2	**MAX-LABIAL >> CONTIG**; MAX-LABIAL >> MAX-DORSAL >> MAX-CORONAL; **ANCHOR-L >> CONTIG**	20%	25%

5.1.3.2 stop-fricative

In RM's data there was a tendency to delete C1 in stop-fricative clusters (70%, 7/10) and in SR's data the distribution was near even (43%-57%, 9-12). Table (54) presents examples:

(54) Reduction in stop-fricative clusters

Child	Age	Child's production	Target word	Gloss	Deleted consonant
RM	1;05.22, 2;09.17	ki	kxi	'you take fm.'	C2
	1;11.18	viʃ	kviʃ	'road'	C1
	1;11.18-2;09.29	xi	kxi	'you take fm.'	C2
	2;09.29	faʁ	kvaʁ	'already'	C1
SR	1;06.20, 1;11.02	fiθ	kfi¢	'spring'	C1
	1;06.26-1;09.27	do'ʁa	dvo'ʁa	'bee'	C2
	1;07.09, 1;07.17	da'ʁa	dvo'ʁa	'bee'	
	1;07.09	va'ʁa	dvo'ʁa	'bee'	C1
	1;07.23	vi'θa	kvi'sa	'laundry'	C1
	1;08.03, 1;08.10, 1;08.24	ki'θa	kvi'sa	'laundry'	C2
	1;09.27	vi'na	gvi'na	'cheese'	C1
	1;11.16	fa'fot	kfa'fot	'gloves'	C1
	2;00.00	xi	kxi	'you take fm.'	C1
	2;02.22	vaʁ	kvaʁ	'already'	C1
	2;02.22	'xelet	'txelet	'light blue'	C1

Here too, the deletion of the less sonorous stop can be accounted for by the high ranking of CONTIG while the deletion of the fricative can be accounted for by the dominance of *F-ONS over *S-ONS and CONTIG:

(55) Constraint rankings for stop-fricative clusters

Deletion	Constraint rankings	RM	SR
C1	**CONTIG >> *F-ONS** >> *S-ONS	70%	43%
C2	***F-ONS >> CONTIG**; *F-ONS >> *S-ONS	30%	57%

5.1.4 Reduction patterns - summary

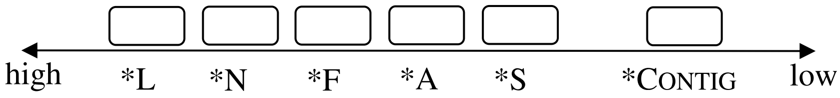
The children's reduction patterns offer evidence for the two main effects found in Ben-David (2001): sonority and contiguity. Sonority has a major effect in C-liquid clusters, where a clear tendency for C2 deletion is found in both children's data. However, there is evidence for a sonority based selection in other clusters as well, more so in SR's data. The effect of contiguity is more prominent and it appears, to some degree, in every cluster. It is mostly apparent in stop-stop and *s*-stop clusters, where both children showed a clear tendency to delete C1, and also in stop-*s* and *s*-fricative in SR's data and stop-fricative and *s*-nasal in RM's. The influence of left edge preservation in cluster reduction was also found in the data, as well as a possible influence for place of articulation. These were much less common, though, and usually did not represent a tendency. The effect of left edge anchoring appeared in RM's reductions in *s*-fricative clusters, where she deleted mostly C2, and also in the few deletions of C2 in *s*-stop and stop-stop clusters. Faithfulness to place of articulation was suggested as an alternative explanation to deletions of C2 in stop-stop clusters.

Some degree of variation is evident in almost every cluster type in each of the children's data, and one strict ranking of constraints cannot account for the reductions of either child. This variation is found among and within cluster types, as well as within words, sometimes in the same recording session. There is no clear distinction between RM and SR with respect to the reduction pattern they follow: Both children follow the sonority pattern to some extent and both exhibit a large number of contiguity-based reductions, but neither is consistent. The theoretical model which aims to explain the large amount of within-child variability is discussed next.

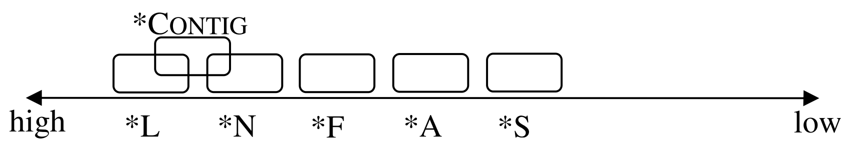
5.1.5 Variability in cluster reduction

Within the model of gradient constraint ranking adopted here, the observed variability in the children's reductions is accounted for by the overlap in constraint ranges and the gradual change in the position of constraints on the ranking scale. To demonstrate this, we can consider the interaction between CONTIG and the sonority constraints, which reflects the variation between the two mostly applied reduction patterns, and make the following assumptions:

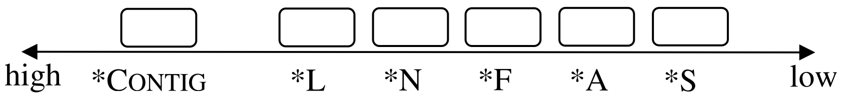
a. The ranking values of (all) the sonority constraints are initially higher than the ranking value of CONTIG, leading to the application of the sonority pattern in early reductions. This is illustrated below:



b. During the acquisition process, the values of both CONTIG and the sonority constraints are modified in small steps so that their relative position with respect to each other, and therefore the overlap in their ranges, gradually changes. This process allows for variable ordered rankings of CONTIG and (some of) the sonority constraints at different evaluations and as a result for variation in output forms. For example, if the ranges of CONTIG and *L-ONS overlap, there can be variation between sonority-based deletions (C2 deletion) and contiguity-based deletions (C1 deletion) in C-liquid clusters, resulting from variable rankings of *L-ONS and CONTIG. Moreover, the range of CONTIG can overlap simultaneously with the ranges of two constraints located consecutively in the hierarchy. This way it is possible, at some probability rate, for CONTIG to be ranked above the higher constraint and below the lower. For example, if the range of CONTIG overlaps with the ranges of both *L-ONS and *N-ONS, CONTIG can be ranked above *L-ONS and below *N-ONS at different evaluations, so that C1 deletion in C-liquid can occur variably (at some low probability rate) with C2 deletion in C-nasal clusters. The following is an illustration:

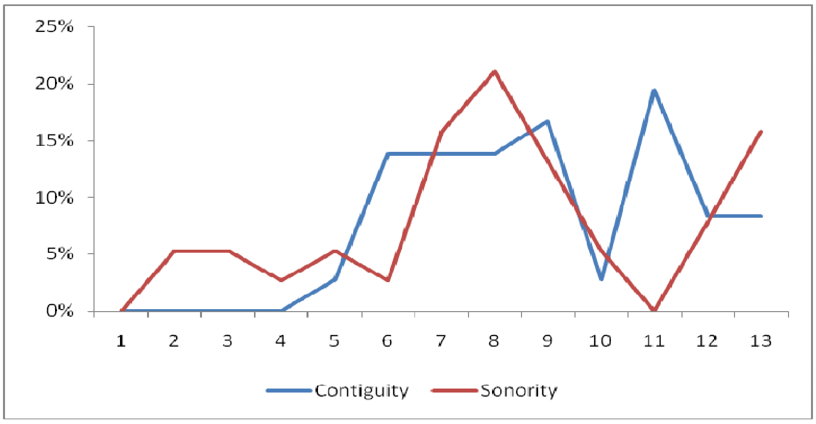


c. By the end of the acquisition process the ranking value of CONTIG is higher than the ranking value of the higher ranked sonority constraint:

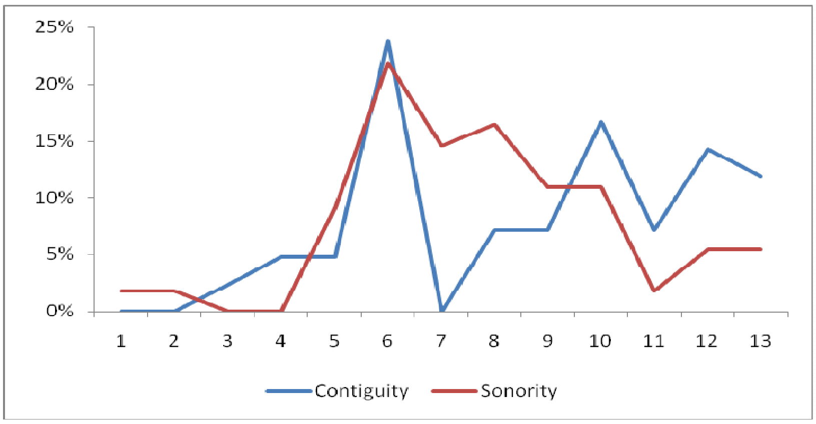


Due to the small sample size, it is difficult to test these assumptions based on probability rates of C1 versus C2 deletion in individual cluster types across time. The charts in (56) and (57) compare total percentages of contiguity-based deletions and sonority-based deletions across time (by session group). The number of contiguity-based deletions includes C1 deletions in all clusters but *s*-stop, in which C1 deletion is due to both sonority and contiguity. The number of sonority-based deletions includes all C2 deletions that were attributed to relative sonority in the above discussion.

(56) RM: Contiguity vs. sonority by session group (types per session)



(57) SR: Contiguity vs. sonority by session group (types per session)



As the charts show, the earliest reductions in both children's data are influenced by sonority; untill period 5 for RM and period 2 for SR. These results support the assumption that CONTIG (as the rest of the faithfulness constraints) is initially located below the sonority hierarchy (as the rest of the markedness constraints) on the ranking scale. This is similar to the first phase of cluster reduction suggested in Ben-David (2001). However, both patterns are evident throughout the rest of the periods, and they do not seem to represent discrete stages of development. There is no evidence for the final position of CONTIG above the sonority constraints, but it may be found in later periods of development.

As for the assumption regarding a gradual change in the position of CONTIG with respect to the sonority hierarchy, it cannot be tested against the above charts. The charts present sonority-based deletion versus contiguity-based deletion in all types of clusters, and the quality of C2 (the more sonorous consonant) is not reflected in them. The quality of C2 determines the relevant sonority constraint in competition with CONTIG, and therefore the position of CONTIG with respect to individual sonority constraints is not depicted in the charts. The charts only suggest, given their sporadic nature, that the two patterns occur during most of the acquisition process.

An examination of individual reductions in different cluster types poses some difficulty for the assumption of gradual change within the model suggested here, because there is evidence for an impossible simultaneous overlap of CONTIG with sonority constraints that are too far apart in the hierarchy. As illustrated above in (b), the range of CONTIG can overlap simultaneously with two consecutive sonority constraints, such as *L-ONS and *N-ONS. It is impossible, however, for CONTIG to overlap simultaneously with two constraints positioned further apart in the hierarchy, *L-ONS and *F-ONS for instance. This is because the model assumes the same standard deviation for every constraint, so that the ranges of possible values have the same "width", and therefore a single constraint cannot be freely ranked with respect to a fixed hierarchy of constrains (i.e. a floating constraint, as suggested in Reynolds 1994 and Nagy and Reynolds 1997; see Boersma and Hayes 2001).

However, exactly such a ranking can explain some of the children's reductions. For example, both children have deletions of C2 in C-fricative clusters that occurred later than C1 deletions in C-liquid clusters. This means that CONTIG is ranked below *F-ONS after it had already been promoted above *L-ONS (or at least its range overlaps with both *L-ONS and *N-ONS). As long as these patterns result from the interaction between CONTIG and the sonority constraints, an analysis of CONTIG as a floating constraint, freely ranked against the entire sonority hierarchy, provides a plausible explanation for them, and it is difficult to account for them within a model that does not allow such an analysis. There is room, then, for further examination of this issue. Still, a model of gradient ranking and reranking accounts for the variability in cluster reduction better than a stage-by-stage reranking process. Furthermore, it accounts well for the variability between simplification strategies. This is discussed in §5.11. In the following sections I present the other simplification strategies found in the data.

5.2 Vowel epenthesis

Epenthesis was the second most common simplification strategy in the data of both children (RM 12% (54/456), SR 8% (21/261)), and its frequency is higher than found in other studies of Hebrew and other languages (see §1.2 above). Many of the insertions occurred in derived target words that do not contain a cluster in their base (RM 43% (23/54), SR 67% (14/21)), as exemplified in (58):

(58) Epenthesis in derived target words

Child	Age	Child's production	Target word	Gloss	Base
RM	2;00.16, 2;01.16	keta'na	kta'na	'small fm. sg.'	katan
	2;01.19	gado'la	gdo'la	'big fm. sg.'	gadol
	2;02.11	kato'iim	gdo'lim	'big ms. pl.	gadol
	2;01.19	gavo'aa	gvo'ha	'tall fm. sg.'	gavoa
	2;06.12	gama'lim	gma'lim	'camels'	gamal
	2;09.06	baʁa'kim	bʁa'kim	'lightning pl.'	baʁak
	2;02.11	¢ave'im	¢va'im	'colors'	¢eva
	2;05.29	ʃefa'nim	ʃfa'nim	'rabbits'	ʃafan
	2;06.12	sevivo'nim	svivo'nim	'tops'	sevivon
	2;01.12	ʃini'ja	ʃni'ja	'second fm.'	ʃeni
SR	2;02.27	gedo'la	gdo'la	'big fm. sg.'	gadol
	2;03.2	'geðeʁim	gza'ʁim	'carrots'	gezeʁ
	2;03.24	peθa'ot	p¢a'im	'wounds'	pe¢a
	1;03.14, 1;03.19, 1;04.24	'tini	tni	'you fm. sg.' give'	ten
	2;03.24	gama'lim	gma'lim	'camels'	gamal
	1;10.26	kale'vim	klavim	'dogs'	kelev
	2;02.27	θagu'ʁim	sgu'ʁim	'closed pl.'	saguʁ
	2;04.03	θevi'vim	svivo'nim	'tops'	sevivon
	2;03.24	θaʁe'tim	sʁa'tim	'movies'	seʁet

The percentage of epenthesis in such derived words is higher than it is in all other words (non-derived, and derived where the base has a cluster), but it is still only second to cluster reduction:

(59) Epenthesis vs. reduction in derived target words

	Derived with CVC in base					Non-derived + derived with CC in base				
	Total	Epenthesis		Reduction		Total	Epenthesis		Reduction	
RM	158	23	15%	31	20%	298	31	10%	61	20%
SR	79	14	18%	28	35%	182	7	4%	85	47%

It is possible, then, that epenthesis is applied more often in derived target words with CVC in the base of the suffix due to paradigm uniformity (see §1.2). But as other simplification strategies are also applied (including a few instances of metathesis), the effect of *COMPLEX in these productions is not excluded.

Most of RM's other insertions and all of SR's occurred in non-derived monosyllabic words (RM 33% (18/54), SR 33% (7/21)), as in (62).[12]

(60) Epenthesis in non-derived monosyllabic words

Child	Age	Child's production	Target word	Gloss
RM	2;00.30	ke'¢at	k¢at	'a little'
	2;05.27	ke'vaʁ	kvaʁ	'already'
	2;06.29	də'vas	dvaʃ	'honey'
	2;02.25, 2;03.29	ka'mo	kmo	'like'
	2;04.05 2;04.19	ke'mo	kmo	'like'
	2;01.06	ko'lum	klum	'nothing'
	1;10.28	ʃə'vau	zvuv	'fly'
	1;10.28	ʃi'buux	zvuv	'fly'
	2;00.30	ta'vuv	zvuv	'fly'
	2;01.06	tʃe'vi	¢vi	'gazelle'
SR	1;07.09, 1;08.24, 1;09.19	ka'viθ	kviʃ	'road'
	1;07.09	kə'viθ	kviʃ	'road'
	2;02.02	ke'mo	kmo	'like'
	1;7.23, 1;10.17	ku'lum	klum	'nothing'
	2;01.25	tθe'vi	¢vi	'gazelle'

The table in (61) compares epenthesis and reduction in monosyllabic words and in polysyllabic words:

(61) Epenthesis vs. reduction in monosyllabic target words

	Monosyllabic words					Polysyllabic words				
	Total	Epenthesis		Reduction		Total	Epenthesis		Reduction	
RM	186	18	10%	34	18%	270	36	13%	58	21%
SR	67	10	15%	21	31%	194	11	6%	92	47%

[12] RM had no insertions in derived monosyllabic words, but SR had a few: all three in *tni* 'you fm. sg. give', where he produced *'tini* (see (50) above). However, *'tini* could also correspond to *'tni li* 'you fm. sg. give me', in which case there is cluster reduction and replacement of *l* with *n*, or metathesis of *n* and *i* with deletion of *l*.

Relative to the total number of monosyllabic target words, RM's percentage of epenthesis is a little lower than it is in polysyllabic words. SR's percentage is higher, suggesting a stronger inclination of SR to insert a vowel between the consonants when monosyllabic words are concerned. However, other simplification strategies occurred in monosyllabic words, implying that vowel epenthesis in these words is motivated by the desire to simplify clusters and not only by word minimality restrictions (see §1.2).

Epenthesis in non-derived polysyllabic target words and derived polysyllabic words that contain a cluster in their base occurred in RM's data only (in 24% of her insertions (13/54)). Examples are brought in (62):

(62) RM – epenthesis in polysyllabic target words

Age	Child's production	Target word	Gloss
2;01.19	tibo'ʁim	dvo'ʁim	'bees'
2;01.19	ge'lida	'glida	'ice cream'
1;04.23, 1;07.10	ʃə'taim	'ʃtaim	'two fm.'
2;00.09	se'pak	spa'geti	'spaghetti'
2;00.30	tese'teja	¢fardea	'frog'
2;01.06	seje'teja	¢fardea	'frog'
2;00.09, 2;02.04	ʃi'naim	'ʃnaim	'two'
2;08.24	¢ə'mone	'ʃmone	'eight'

The higher proportion of epenthesis in RM's data, compared with SR's, may stem from her tendency to extend words (see Zaidenberg and Albert 2008 for RM's filler syllables). This tendency is exemplified in her productions of filler syllables in target words with clusters (although it is not unique to such target words: e.g. *ə'ken* for *ken* 'yes'):

(63) RM's filler syllables

Age	Child's production	Target word	Gloss
2;00.16	iʃ'tajim	ʃ'taim	'two fm.'
2;01.06	je'ʃnaim	'ʃnaim	'two m.'
2;01.06	'ostai	ʃ'taim	'two fm.'
2;01.12	akvi'na	gvi'na	'cheese'
2;02.04	e'ʃnaim	'ʃnaim	'two m.'
2;03.01	ʔegdo'la	gdo'la	'big fm. sg.
2;04.05	fiʃme'aa	¢me'a	'thirsty'
2;04.19	'ʔeʃve	ʃvi	'you sit down fm.'

In a few cases she even inserted a syllable in addition to the simplification strategy she applied:

(64) RM – filler syllable and simplification

Age	Child's production	Target word	Gloss
2;00.30	evave'deja	¢far'dea	'frog'
2;03.01	ə'xi	kxi	'you take fm.'
2;04.12	ʔe'xi	kxi	'you take fm.'
2;05.29	e¢ami'dim	e¢ami'dim	'bracelets'

As for the distribution of epenthesis, the following scales present percentages of insertions by cluster type, from the most frequent (on the left) to the least frequent. The percentages are calculated out of the total number of productions for each cluster type.

(65) RM - epenthesis by cluster type

s-fricative	stop-nasal	stop-stop	*s*-nasal	*s*-stop	stop-fricative	stop-liquid	stop-*s*	*s*-liquid	fricative-liquid
25% (13/51)	20% (11/56)	15% (10/65)	14% (7/50)	8% (3/40)	7% (5/76)	6% (4/66)	3% (1/39)	0% (0/6)	0% (0/7)

(66) SR - epenthesis by cluster type

stop-nasal	stop-*s*	*s*-liquid	*s*-fricative	stop-fricative	stop-liquid	*s*-stop	stop-stop	fricative-liquid	*s*-nasal
26% (5/19)	18% (3/17)	14% (1/7)	11% (3/27)	8% (3/38)	6% (4/72)	4% (1/23)	3% (1/34)	0% (0/2)	0% (0/22)

There are insertions in both obstruent-obstruent and obstruent-sonorant clusters and the percentage in each is the same as in the general calculation (RM 12%: 32/271 in obstruent-obstruent, 22/185 in obstruent-sonorant; SR 8%: 11/139 in obstruent-obstruent, 10/122 in obstruent-sonorant). SR had a smaller number of insertions and it is difficult to establish a pattern with respect to the environment in which they occur. In RM's case it seems that the cluster types which have a larger percentage of vowel insertions are the ones in which the consonants have similar features. For example, in stop-stop and *s*-fricative clusters the consonants have the same manner of articulation (when the sibilant is an affricate the consonant is released as a fricative); in stop-nasal both consonants are [-continuant]; in *s*-nasal most clusters consist of two coronals.

The inserted vowel is usually an *e*, the epenthetic vowel in Hebrew, or a *ə* (e.g. *ke'mo* for *kmo* 'like', *ʃə'taim* for *'ʃtaim* 'two'), but in some cases an *a* is inserted (e.g. *ka'viθ* for *kviʃ* 'road'). The vowel can also be identical to the vowel of the base in derived words (e.g. *θagu'ʁim* for *sgu'ʁim* 'closed pl.', where the base is *sa'guʁ*) or assimilate to the adjacent or final vowel (e.g. *ku'lum* for *klum* 'nothing', *tibo'ʁim* for *dvo'ʁim* 'bees').

Not taking into account the additional constraints which motivate epenthesis in monosyllabic words and derived words, the constraint rankings that account for epenthesis as a cluster simplification strategy are *COMPLEX >> DEP and MAX >> DEP and MAX >> CONTIG. The sonority constraints are not at play here.

(67) *COMPLEX >> DEP; MAX >> DEP; MAX >> CONTIG

kviʃ → *kə'viθ* 'road' (SR, 1;07.09)

/kviʃ/	*COMPLEX	MAX	DEP	CONTIG
a. kviʃ	*!			
b. viʃ		*!		
c. kiʃ		*!		*
d. ☞ kə'viθ			*	*

The children’s insertions occurred throughout the study, unlike in previous studies of Hebrew (Ben-David 2001, Adi-Bensaid and Ben-David 2010; see §1.3 above) and other languages (e.g. Greenlee 1974, Fikkert 1994, Mcleod et. al. 2002, Freitas 2003), which found that epenthesis occurred later in development than cluster reduction and just before faithful production. I will return to the developmental aspect later (§5.11) and will now briefly present the other simplification strategies and phenomena.

5.3 Metathesis

There were only a few cases of metathesis in the data of both children (RM 1% (5/456), SR 3% (9/261)), all brought in (68) below. The scarcity of these productions is similar to the findings of previous studies (see §1.2).

(68) Metathesis

Child	Age	Child's production	Target word	Gloss
RM	1;11.18	tu'mot	tmu'not	'pictures'
	1;11.18	viʃ	ʃvi	'you sit down fm.'
	2;00.16	ʃel'ʃa	ʃlo'ʃa	'three ml.'
	2;01.12	siʁ'ka	zʁika	'injection'
	2;03.24	vuʁ'dim	vʁu'dim	'pink ml. pl.'
SR	1;06.20	beʁ'xa	bʁe'xa	'swimming pool'
	1;09.19, 1;09.27, 1;11.07	'taʁtoʁ	'tʁaktoʁ	'tractor'
	2;00.05	'kuθteʁ	'skuteʁ	'scooter'
	2;01.11	bol'dini	blon'dini	'blond'

As found in Ben-David (2001), in clusters consisting of consonants with different sonority levels, the more sonorous consonant is moved to the coda position, and it is possible that along with the avoidance of complex onsets, the sonority hierarchy influences these productions. The production of *'kuθteʁ* for *'skuteʁ* 'scooter', being the only case of metathesis in a falling sonority cluster, best demonstrates this: the least sonorous stop is produced in onset position and the fricative is moved to the coda. In most other cases the second consonant and the vowel are reversed, since the second consonant is the more sonorous.

The higher ranking of *COMPLEX, MAX and DEP with repect to LINEARITY, as well as the sonority hierarchy, account for most of the above productions:

(69) *COMPLEX >> LINEARITY; MAX >> LINEARITY; DEP >> LINEARITY; *L-ONS >> *F-ONS

vʁu'dim → vuʁ'dim 'pink m. pl.' (RM 2;03.24)

/vʁu'dim/	*COMPLEX	MAX	DEP	LINEARITY	*L-ONS	*F-ONS
a. vʁu'dim	*!				*	*
b. vu'dim		*!				*
c. ʁu'dim		*!			*	
d. veʁu'dim			*!		*	*
e. ʁuv'dim				*	*!	
f. ☞ vuʁ'dim				*		*

The sonority hierarchy cannot account for the change in the position of the consonants in *viʃ* for *ʃvi* 'you sit down fm.', however, because both are fricatives. A possible explanation for this production is a preference for the production of the labial at the beginning of the word, which perhaps emerges when relative sonority is not at play (otherwise *tmu'not* would be produced as *mut'not* or *mu'tot* rather than *tu'mot*). This preference is also found in onset singletons (e.g. *pa'tat* for *taba'at* 'ring', *'budi* for *'dubi* 'teddy bear') (cf. Kappa 2002, where labial-favoring Metathesis is reported in the acquisition of Greek). An Alignment constraint favoring a labial word-initially has to be ranked above LINEARITY in order for this production to take place, but this interaction is not further discussed here.

The few instances of metathesis started occurring around the time that correct productions began to appear and they occurred simultaneously with epenthesis, cluster reduction, coalescence and other phenomena. The co-occurrence of metathesis and cluster reduction is different than the findings in Ben-David (2001), where metathesis, alongside epenthesis, was considered part of a developmental stage which appears after cluster reduction and before production of a cluster (see §5.11 for further discussion of development).

5.4 Coalescence

Instances of coalescence were found in RM's data only, and they were scarce (1%, 6/456), as predicted by previous studies (see §1.2). All of these instances are brought in (70):

(70) RM - Coalescence

Age	Child's production	Target word	Gloss
2;00.09	po'ʁa	dvo'ʁa	'bee'
2;02.04	tat	k¢at	'a little'
2;05.15	tits	klips	'clip'
2;05.27	zo'ʁa	dvo'ʁa	'bee'
2;05.29	bo	kmo	'like'
2;11.28	ka'xim	pʁa'xim	'flowers'

As mentioned above (§3.2.2), there is more than one way to interpret these productions, and most of them can also be interpreted as the deletion of C1 and stopping of C2. When interpreted as coalescence, the observation is that usually the manner of the first consonant and the place of the second consonant are preserved, similar to the findings of other studies in both Hebrew and other languages (Ben-David 2001, Chin and Dinnsen 1992, Gnanadesikan 1995/2004, Bensaid 2006). These cases further demonstrate the preference for low sonority onsets, as the produced consonant is a stop. The constraint rankings that accounts for them are the following:

(71) *COMPLEX >> UNIFORMITY; MAX >> UNIFORMITY; DEP >> UNIFORMITY; LINEARITY >> UNIFORMITY; *F-ONS >> *S-ONS

dvo'ʁa → po'ʁa 'bee' (RM 2;00.09)

/dvo'ʁa/	*COMPLEX	MAX	DEP	LINEARITY	UNIFORMITY	*F-ONS	*S-ONS
a. dvo'ʁa	*!					*	*
b. do'ʁa		*!					*
c. vo'ʁa		*!				*	
d. devo'ʁa			*!			*	*
e. dov'ʁa				*!			*
f. zo'ʁa					*	*!	
g. ☞ po'ʁa					*		*

zo'ʁa for *dvo'ʁa* is the only case where the produced consonant has the manner of the second consonant and the place of the first consonant, and a fricative is produced instead of a stop. Curiously, in this case the more marked manner of articulation in syllable onset – the fricative – is preserved. Also, contrary to findings in English (Gnanadesikan 1995/2004, Pater and Barlow 2003), the labial place of articulation is not preferred here (compare also the discussion of metathesis above).

The above productions occurred simultaneously with productions involving epenthesis, metathesis, cluster reduction, cluster deletion and adult clusters. As they are so few, it is difficult to assess their distribution over time and compare it against the finding that coalescence is a transitional phase between stages (Chin and Dinnsen 1992, Adi-Bensaid and Ben-David 2010) (see §5.11 for further discussion).

5.5 Non-assimilatory substitution

In some productions the cluster consonants were replaced with a different single consonant which did not correspond to any of the cluster consonants.

(72) Non-assimilatory substitution

Child	Age	Child's production	Target word	Gloss
RM	1;11.18	he'¢a	k¢i'¢a	'meatball'
	1;11.18	'katoo	'tʁaktoʁ	'tractor'
	2;00.16	fe'noot	tmu'not	'pictures'
	2;00.16	hisa'jaa	¢faʁ'dea	'frog'
	2;00.30	he'deja	¢faʁ'dea	'frog'
	2;00.30	ha'tejaa	¢faʁ'dea	'frog'
	2;02.04	'voxe	sʁox	'shoe lace'
SR	2;02.22	'katik	'plastik	'plastic'
	2;03.24	duxi'jot	zxuxi'jot	'glass'

These productions do not represent a distinct simplification strategy, and the constraints motivating them are not discussed here. They are brought together simply because in all of them only one consonant is produced, different than the original consonants, and they do not fall into any of the other categories.

A replacement of the onset with an *h*, as in RM's productions of *¢faʁ'dea* 'frog' and *k¢i'¢a* 'meatball', occurred in target words with simple onsets as well (e.g. *he'duax* for *pa'tuax* 'open' at 2;00.09, *ha'vat* for *taba'at* 'ring' at 2;00.30, *he'puʁ* for *si'pur* 'story' at 2;01.19). Similarly, Fikkert (1994) found that *h* is sometimes produced instead of singletons and clusters in the speech of Dutch acquiring children.

RM's production of *'katoo* for *'tʁaktoʁ* 'tractor' seems to involve a deletion of the entire cluster and reversal of the coda and the vowel. But it can also be interpreted as coalescence (manner of C1 and place of C2) or as the deletion of C1 and stopping of C2 (see §5.4).

In her production of *fe'noot* for *tmu'not* 'pictures' RM possibly deleted C1 and turned the nasal into a fricative (as she did in *fa* for *ma* 'what' and *fi* for *mi* 'who'). *voxe* for *sʁox* 'shoe lace' can be interpreted as the deletion of C2 and fronting of C1.

SR's production of *'katik* for *'plastik* 'plastic' can be a result of consonant harmony, where the initial consonant assimilates to the final consonant, following the deletion of either one of the consonants. His production of *duxi'jot* for *zxuxi'jot* 'glass' is possibly the deletion of C2 and stopping of C1.

5.6 Reduplication

Only four cases of onset reduplication were found in target words containing clusters (under 1% in both children's data), and these are brought in (73).

(73) Reduplication

Child	Age	Child's production	Target word	Gloss
RM	2;00.16	te'teea	¢faʁ'dea	'frog'
	2;00.16	nə'noot	tmu'not	'pictures'
SR	1;05.08	'dida	'glida	'ice cream'
	1;09.27	va'vim	kla'vim	'dogs'

Most of these productions can be interpreted in other ways as well as reduplication: *te'teea* for *¢far'dea* 'frog' can be interpreted as the deletion of C2 and stopping of C1; *nə'noot* for *tmu'not* 'pictures' and *'dida* for *'glida* 'ice cream' can be interpreted as coalescence. Since the produced consonant is identical to the consonant of the following syllable, I treat these cases as reduplication.

Reduplication was more frequent in target words containing simple onsets in the first syllable, and it was found in such words even around the times that the above productions occurred. The following are examples:

(74) Reduplication in singletons

Child	Age	Child's production	Target word	Gloss
RM	1;08.01	ta'tom	ka'tom	'orange'
	2;00.16	ta'tan	ka'tan	'small ml. sg.'
	2;01.12	mama'ja	nemala	'ant'
SR	1;06.02	na'nas	pa'nas	'flashlight'
	1;07.17	di'dal	mig'dal	'tower'
	1;09.19	'tata	'savta	'grandmother'

As this phenomena is not specific to complex onsets (Ben-David 2001, Adi-Bensaid and Ben-David 2010), I do not treat it as a cluster simplification strategy and do not discuss the constraints responsible for such productions. However, it is still possible that *COMPLEX affects these productions in addition to those other constraints.

5.7 Cluster deletion

There were a few productions where the entire cluster was deleted (RM under 1% (3/456), SR 3% (9/291), as found in other studies (see §1.2). These productions are brought in (75):

(75) Cluster deletion

Child	Age	Child's production	Target word	Gloss
RM	1;06.05	'ato	'tʁaktoʁ	'tractor'
	2;00.30	e'tejaa	¢faʁ'dea	'frog'
	2;06.12	'ʔaktoʁ	'tʁaktoʁ	'tractor'
SR	1;07.09	ʔa'bati	spa'geti	'spaghetti'
	1;07.17	ʔa'pati	spa'geti	'spaghetti'
	1;07.23, 1;09.00	'ʔitθel	'ʃni¢el	'schnitzel'
	1;08.03	'ʔaim	'ʃtaim	'two fm.'
	1;08.24	impθ	ʃʁimps	'shrimps'
	1;09.09	ʔa'na	kta'na	'small fm. sg.'
	1;09.09	'ʔupi	'snupi	'Snoopi'
	2;02.06	a'kin	dʁa'kon	'dragon'

Initial onset deletion was reported as the initial stage of cluster acquisition (Greenlee 1974, Ingram 1976, McLeod et al. 2001, Ben-David 2001). However, this is another wider phenomenon which affects both simple and complex onsets (Ben-David 2001, Adi-Bensaid and Ben-David 2010), and it is not regarded here as a cluster simplification strategy, even though the prohibition on consonant clusters may be an additional force motivating deletions in target words with clusters. Indeed, deletions in target words with initial simple onsets, as exemplified in (76), occurred more frequently, and they occurred simultaneously with deletions in target words with clusters.

(76) Onset deletion in target words with simple onsets

Child	Age	Child's production	Target word	Gloss
RM	1;05.29	a'du	ka'duʁ	'ball'
	1;06.12	u'ba	bu'ba	'doll'
	1;08.07	'eve	'devek	'glue'
	1;10.13	ə'ta	mi'ta	'bed'
	2;00.16	i'tʃe	ki'se	'chair'
	2;02.25	oj	boi	'you (fm. sg. come)'
	2;06.12	ʔalo'nim	balo'nim	'baloons'
	2;06.29	a'ze	ka'ze	'such'
	2;11.28	o	bo	'you (m. sg.) come'
SR	1;05.04	'ʔagell	'ʁegel	'leg'
	1;06.26	a'nana	banana	'banana'
	1;07.09	ʔa'duʁ	kaduʁ	'ball'
	1;07.17	'ʔefeʁ	sefeʁ	'book'
	1;07.23	'ʔiaθ	'tiras	'corn'
	1;08.03	ʔa'meʁ	na'meʁ	'leopard'
	1;08.10	ʔa'gevet	magevet	'towel'
	1;09.00	i'nok	ti'nok	'baby'
	1;09.27	ʔa'van	la'van	'white'
	1;10.07	ʔa'lil	ga'lil	'roll'
	1;10.26	ʔaga'faim	maga'fayim	'boots'
	1;11.07	ʔafə'lu	naf'lu	'fall past pl'

Development-wise, the instances of cluster deletions do not appear to represent an early stage. In SR's data they did not appear in the earliest recording sessions, but they began later and occured simultaneously with correct productions, as well as reduction, epenthesis and metathesis. In RM's data there were only three such productions, and they appeared in both early and late recording sessions, where cluster reduction, epenthesis, metathesis, coalescence and correct productions also occurred.

5.8 Syllable deletion

In some early productions, all brought in (77), the initial syllable was deleted; RM 1% (5/456), SR 2% (4/261).

(77) Syllable deletion

Child	Age	Child's production	Target word	Gloss
RM	1;05.29	'tei	¢faʁ'dea	'frog'
	1;05.29	'taax	¢faʁ'dea	'frog'
	1;07.03	'ta	k¢i'¢a	'meatball'
	1;11.18	'taj	sfa'taim	'lips'
	2;00.16, 2;00.30	'teja	¢faʁ'dea	'frog'
SR	1;05.21	vim	zvu'vim	'flies'
	1;06.26	'ego	fla'mingo	'flamingo'
	1;06.26, 1;07.09	'tina	kleman'tina	'tangerine'

Syllable truncation is a common phenomenon in language acquisition (Fikkert 1994, Demuth and Fee 1995, Demuth 1996b, Kehoe 2000, Ben-David 2001, Adam 2002), and just as onset deletion and onset reduplication it is not unique to target words with initial clusters. This is supported by the frequent occurrence of truncation in target words with initial simple onsets, as exemplified below:

(78) Syllable deletion in target words with simple onsets

Child	Age	Child's production	Target word	Gloss
RM	1;05.29	hof	¢a'hov	'yellow'
	1;06.05	'toax	lif'toax	'to open'
	1;09.10	¢e¢	mo'¢e¢	'pacifier'
	1;10.13	pe'ka	madbe'ka	'sticker
	1;11.18	e'vizaa	tele'vizya	'television'
	2;00.09	se'it	masa'it	'truck'
	2;00.16	¢ah	'me¢ax	'forehead'
	2;00.30	ma'li	nema'lim	'ants'
	2;00.30	tan	ka'tan	'small m. sg.'
SR	1;04.03	'puax	ta'puax	'apple'
	1;05.21	'nana	banana	'banana'
	1;06.26	xaθ	na'xaʃ	'snake'
	1;07.09	tuv	ʁatuv	'wet ml. sg.'
	1;07.17	xol	ka'xol	'blue ml. sg.
	1;08.03	meʁ	na'meʁ	'leopard'
	1;08.24	ki'ja	sukaʁ'ya	'candy'
	1;09.00	ga'faim	magafayim	'boots'
	1;09.09	ʔa'dim	yeladim	'children'
	1;09.27	dal	mig'dal	'tower'
	1;10.26	ga'laim	rag'layim	'legs'

5.9 Non-target cluster

Productions of initial clusters that are different than the target cluster were also found (RM 4% (17/456), SR 2% (5/261)), all presented in (79):

(79) Non-target clusters

Child	Age	Child's production	Target word	Gloss
RM	1;11.25, 2;00.16	'ʃteja	¢faʁ'dea	'frog'
	2;00.02	'tmoni	'ʃmone	'eight fm.'
	2;00.16	'dzeja	¢faʁ'dea	'frog'
	2;03.29	kvo	kmo	'like'
	2;04.12	kwo	kmo	'like'
	2;04.12	kftat	k¢at	'a little bit'
	2;04.12	ktas	k¢at	'a little bit'
	2;04.12	tnaʃ	dvaʃ	'honey'
	2;04.19	kmə'xa	sme'xa	'happy fm. sg.'
	2;05.27	'dlida	'glida	'ice cream'
	2;05.27	'kʁaktoʁ	'tʁaktoʁ	'tractor'
	2;06.12	'fsede	'svedeʁ	'sweater'
	2;08.24	'dlidot	'glidot	'ice creams'
	2;08.24	'tniina	'pnina	'Pnina'
	2;11.14	ktat	k¢at	'a little bit'
	2;11.14	tmol	smol	'left (side)'
	2;11.28	txi	kxi	'you (fm. sg.) take'
SR	1;11.07	kfon	ksilo'fon	'xylophone'
	2;00.05	tva'ʔim	¢va'im	'colors'
	2;00.05	'tkuteʁ	'skuteʁ	'scooter'
	2;01.25	θbi	¢vi	'gazelle'
	2;02.06	ðbuv	zvuv	'fly'

Most of these productions involve substitutions and other phenomena that were found in singletons as well. These include stopping (e.g. RM *tmol* for *smol* 'left side', *tuʃ* for *sus* 'horse'; SR tva'ʔim for ¢va'im 'colors', *tuθ* for *sus* 'horse'), fronting (e.g. RM *txi* for *kxi* 'you (fm. sg.) take', *'texa* for *'kaxa* 'like that'), place assimilation (e.g. RM *'kʁaktoʁ* for *'tʁaktor* 'tractor', *paf* for *kaf* 'spoon', *ki'ʁii* for *ti'ri* 'you (fm. sg.) look'), syllable deletion (e.g. RM 'ʃteja for ¢faʁ'dea 'frog', *'ksem* for *ko'sem* 'magician'; SR *kfon* for *ksilo'fon* 'xylophone', *'fnoa* for *of'noa* 'motorcycle'), the substitution of *w* or *v* for *m* (e.g. RM *kvo* and *kwo* for *kmo* 'like', *we'sati* for *ma'ʦati* 'I (past sg.) found', *vət'ʔim* for *mat'im* 'fitting').

However, in many of the above productions, whether they involve substitutions which are predictable from singletons or not, the consonants in the produced cluster agree in place or manner of articulation: In RM's productions of *ktas* and *ktat* for *kʦat* 'a little bit' and in SR's production of *'tkuteʁ* for *'skuteʁ* 'scooter', the consonants agree in manner. In *'tniina* for *'pnina* 'Pnina', *'dlida* for *'glida* 'ice cream' and *'kʁaktoʁ* for *'tʁaktor* 'tractor' they agree in place. In *tnaʃ* for *dvaʃ* 'honey', *kmə'xa* for *sme'xa* 'happy fm. sg.', *'tmoni* for *'ʃmone* 'eight fm.' and *tmol* for *smol* 'left side', both consonants are [-continuant]. Following Kirk (2008), it is possible to inerpret such productions as assimilation within the cluster which leads to articulatory simplification.

Non-target clusters appeared relatively late (similar to the findings in Greenlee 1974 and Watson and Scukanec 1997, for example). They occurred after correct productions began to occur and simultaneously with reduction, epenthesis, metathesis and coalescence, at a time when the location of *COMPLEX on the ranking scale relative to the faithfulness constraints accounting for these simplification strategies could allow complex onsets, at least in some evaluations (see §5.11).

5.10 Correct production

Productions of adult clusters were very common; RM 56% (254/456), SR 37% (96/261). They did not appear in the earliest recording sessions, but started appearing later, when more attempts to produce target words with initial clusters were made. As can be seen in (80), an attempt was made to determine the beginning of production of adult clusters for each cluster type. The criterion used for this purpose was the production of correct clusters in two consecutive recording sessions for a cluster type. For some cluster types it was impossible to determine the beginning of correct production based on this criterion, mainly because of the small number of total productions for these clusters. In such cases the table specifies "undetermined".

(80) Beginning of adult-like production by cluster type

Cluster type	**RM**	**SR**
stop-stop	2;00.09	2;02.02
stop-*s*	2;03.24	2;01.25
stop-fricative	2;02.25	2;02.06
stop-nasal	2;02.04	2;01.25
stop-liquid (l)	2;05.27	2;01.11
stop-liquid (ʁ)	2;10.03	Undetermined
fricative-liquid	Undetermined	Undetermined
s-stop	2;01.06	2;02.02
s-fricative	undetermined	2;01.11
s-nasal	2;03.24	2;02.02
s-liquid	Undetermined	Undetermined

The order of cluster types by starting ages of correct production is brought below for each child:

(81) Order by beginning of correct production

a. RM: stop-stop > *s*-stop > stop-nasal > stop-fricative > *s*-nasal, stop-*s* > stop-liquid (*l*) > stop-liquid (□)

b. SR: stop-liquid (*l*), *s*-fricative > stop-*s*, stop-nasal > stop-stop, *s*-stop, *s*-nasal > stop-fricative

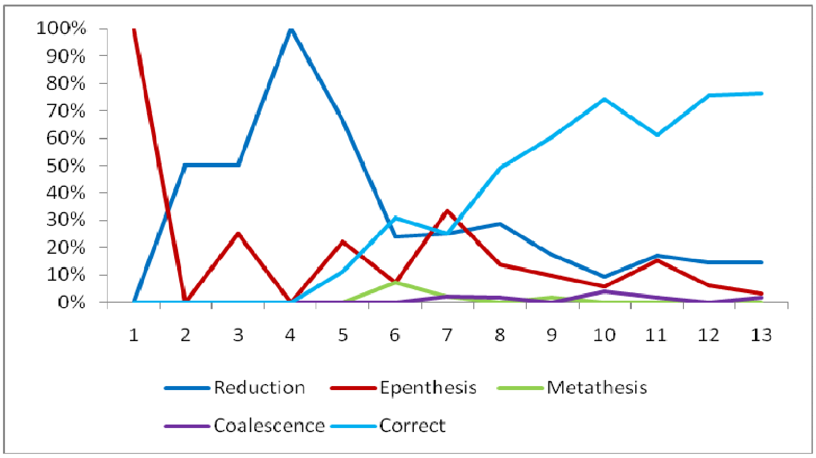
SR's scale is more consistent with previous findings in Hebrew and other languages, which report on an earlier acquisition of obstruent-approximant clusters (e.g. Chin and Dinnsen 1992, Fikkert 1994, Bernhardt and Stemberger 1998, Ben-David 2001), than RM's. However, more data is needed in order to better examine the order of acquisition.

Over time, the general tendency was an increase in the number of correct productions. This gradual progression is consistent with a gradual learning process, as adopted here. I discuss this process in the following section.

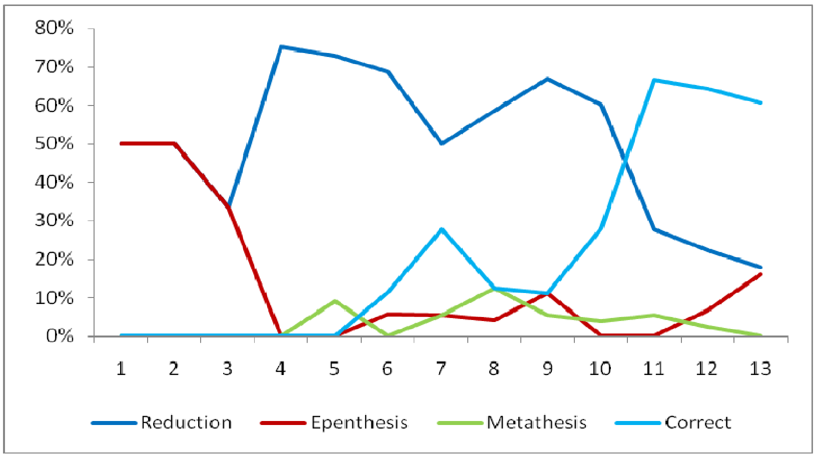
5.11 Variability in simplification strategies

The following charts compare the application of the different simplification patterns – reduction, epenthesis, metathesis and coalescence, as well as correct production, across time. The percentages for each phenomenon are calculated out of the total number of productions in a session group (types per session).

(82) RM – simplification patterns and correct production across time



(83) SR - simplification patterns and correct production across time



It is apparent from the above charts that in both children's data, epenthesis and cluster reduction co-occur across time, even though reduction is in general more common. The change in the relative frequency of these strategies over time does not indicate that they are chronological, as there is no clear rise in the application of epenthesis versus the drop in the application of reduction (which actually correlates with the gradual increase in the frequency of correct productions).

As for metathesis and coalescence, these strategies start to occur later than both cluster reduction and epenthesis, but there is no rise in their application over time to indicate a "substitution" of the preferred simplification strategy. It is possible that the frequency of metathesis and coalescence does not increase because they are rare phenomena, and because correct productions start appearing at the same time. Also, in RM's data these strategies start occurring around the time that the frequency of cluster reduction starts decreasing, seemingly supporting a chronological application of strategies. However, the later appearance of metathesis and coalescence is probably related to the increase in the number of attempts at that time, which allows for even the less common strategies to emerge.

Although it would be useful to examine the relative frequencies of the strategies in later periods of acquisition in order to see if these tendencies continue, the co-occurrence of the simplification strategies, particularly cluster reduction and epenthesis, throughout the study, suggests that they are multiple means to avoid the production of consonant clusters, or to satisfy *COMPLEX, rather than reflections of distinct developmental stages or sub-stages as previously suggested (see §1.2).

Onset reduplication, onset deletion and syllable deletion are also applied simultaneously with the simplification strategies, although reduplication and syllable deletion do not appear in later recording sessions. These phenomena may represent stages in the acquisition of onsets or in the acquisition of prosodic words, but they do not seem to represent stages in the acquisition of consonant clusters. As far as they are motivated by *COMPLEX, they can be viewed as additional means to avoid production of clusters.

Considering the four simplification strategies compared above, their simultaneous application suggests that there is some degree of variation in the relative rankings of the relevant faitfulness constraints - MAX, DEP, LINEARITY and UNIFORMITY, leaving room for different strategies to occur in order to satisfy *COMPLEX. For example, RM produced the word *kmo* 'like' using epenthesis and reduction during the same recording session, so that at one evaluation DEP was the lowest of the faithfulness constraints and at another MAX was the lowest:

(84) *COMPLEX >> DEP; MAX >> DEP; UNIFORMITY >> DEP; LINEARITY >> DEP; *N-ONS >> *S-ONS

kmo → *ka'mo* 'colors' (RM 2;02.25)

/kmo/	*COMPLEX	MAX	LINEARITY	UNIFORMITY	DEP	*N-ONS	*S-ONS
a. kmo	*!					*	*
b. mo		*!				*	
c. ko		*!					*
d. kom			*!				*
e. po				*!			*
f. ☞ ka'mo					*		*

(85) *COMPLEX >> MAX; DEP >> MAX; UNIFORMITY >> MAX; LINEARITY >> MAX; *N-ONS >> *S-ONS; *N-ONS >> CONTIG

kmo → *ko* 'colors' (RM 2;02.25)

/kmo/	*COMPLEX	DEP	LINEARITY	UNIFORMITY	MAX	*N-ONS	CONTIG	*S-ONS
a. kmo	*!					*		*
b. mo					*	*!		
c.☞ko					*		*	*
d. kom			*!					*
e. po				*!				*
f. ka'mo		*!						*

Another example is SR's production of the word *'tʁaktoʁ* 'tractor' using reduction and metathesis during the same recording session, so that MAX was the lowest ranked constraint at one evaluation and LINEARITY at the other:

(86) *COMPLEX >> MAX; DEP >> MAX; UNIFORMITY >> MAX; LINEARITY >> MAX; *L-ONS >> *S-ONS; *L-ONS >> CONTIG

'tʁaktoʁ → 'taktoʁ 'tractor' (SR 1;09.19)

/tʁaktoʁ/	*CMPLX	DEP	LINEARITY	UNIFORMITY	MAX	*L-ONS	CONTIG	*S-ONS
a. tʁaktoʁ	*!					*		*
b.☞ taktoʁ					*		*	*
c. ʁaktoʁ					*	*!		
d. taʁktoʁ			*!					*
e. ɢaktoʁ				*!				*
f. teʁaktoʁ		*!						*

(87) *COMPLEX >> LINEARITY; MAX >> LINEARITY; DEP >> LINEARITY; UNIFORMITY >> LINEARITY; LINEARITY >> *L-ONS; *L-ONS >> *S-ONS

'tʁaktoʁ → 'taʁtoʁ 'tractor' (SR 1;09.19)

/tʁaktoʁ/	*COMPLEX	MAX	DEP	UNIFORMITY	LINEARITY	*L-ONS	*S-ONS
a. tʁaktoʁ	*!					*	*
b. taktoʁ		*!					*
c. ʁaktoʁ		*!				*	
d.☞ taʁtoʁ					*		*
e. ɢaktoʁ				*!			*
f. teʁaktoʁ			*!				*

Within the model of gradient constraint ranking, this variability is attributed to a partial overlap in the ranges of MAX, DEP, LINEARITY and UNIFORMITY, allowing for different rankings to occur at different evaluations. As cluster reduction is the most common strategy, we can assume that although the ranking values of the four constraints are close enough on the scale to allow some overlap between their ranges (i.e. the normal distribution of values around the ranking values), the ranking value of MAX is the lowest, so that the value selected for it at evaluation time (i.e. the selection point) is more often lower than the selection points of the other constraints. DEP, LINEARITY and UNIFORMITY therefore dominate MAX at most evaluations, leading to the less frequent occurrence of epenthesis, metathesis and coalescence than cluster reduction.

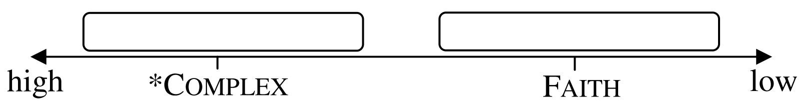
As discussed above (§4), gradual learning assumes that the ranking values of these constraints, as well as the ranking value of *COMPLEX, gradually change over time, so that their relative location on the scale with respect to each other can also change. As we have already seen, there is no indication in the current data that the location of MAX, DEP, LINEARITY and UNIFORMITY with repect to each other changes, as there does not seem to be a correlation between the relative frequencies of the strategies over time, and it is therefore possible that the promotion of these constraints progresses at a similar rate.

There is indication, however, for the gradual demotion of *COMPLEX with respect to the faithfulness constraints, particularly MAX, since a correlation is found between the gradual drop in the frequency of cluster reduction and the gradual increase in the frequency of correct productions. The other strategies are too sparse in order to observe such a correlation, but a gradual change in the location of *COMPLEX and these constraints can also be assumed. An initial location of *COMPLEX above the faitfulness constraints (with no overlap) is supported by the fact that clusters were not produced at all in early productions. Its final location below these constraints is predicted to occur by the end of the acquisition process, but it is still not evident in the data.

The process of cluster acquisition in the framework of gradient constraint ranking and gradual learning is therefore assumed to be as follows:

a. The ranking value of *COMPLEX is initially higher than the ranking value of faithfulness constraints, blocking any production of clusters. This is illustrated below:

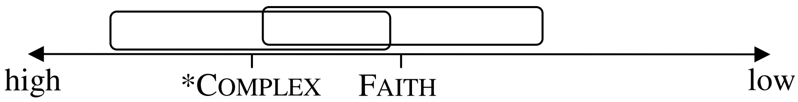
(88) *COMPLEX >> FAITH



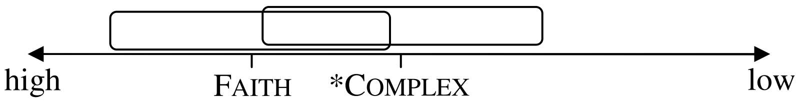
b. During the acquisition process, the values of *COMPLEX and the faithfulness constraints are slowly modified so that their relative position with respect to each other gradually changes. As *COMPLEX demotes and the faithfulness constraints promote, productions of clusters, target and non-target, gradually appear. An overlap between the ranges of the faithfulness constraints with repect to each other allows for some degree of variation in the application of different simplification strategies. Following is an illustration of the variable ranking between *COMPLEX and the faithfulness constraints:

(89) *COMPLEX ~ FAITH

a. *COMPLEX >> FAITH with overlap

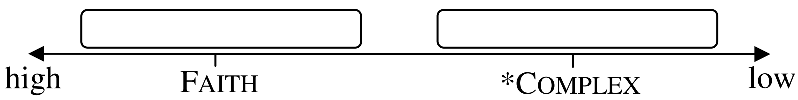


b. FAITH >> *COMPLEX with overlap



c. By the end of the acquisition process, the ranking value of *COMPLEX is higher than the ranking value of the faithfulness constraints, so that clusters are produced correctly. This ranking is illustrated below:

(90) FAITH >> *COMPLEX



6. Conclusion

The thesis studied the simplification patterns in the acquisition of word-initial consonant clusters, as found in the speech of two typically developing Hebrew-acquiring children, revealing the following findings:

a. Most reduction patterns can be explained based on the interaction between contiguity requirements and onset sonority preferences, as found in previous studies of Hebrew acquisition, although sonority plays a bigger role than previously reported. Reduction patterns in *s*-clusters are inconsistent, and they do not necessarily indicate a difference between *s*-clusters and other clusters.

b. Cluster simplification strategies, as well as other phenomena found in production of clusters, do not seem to represent distinct stages in the acquisition of consonant clusters, but different means to prevent the formation of clusters.

c. Variability in simplification patterns can be accounted for within a theoretical model that allows gradient ranking of constraints and gradual learning rather than a stage-by-stage reranking process. An examination of later periods in acquisition than examined in this study and of data obtained from more children would be of interest, as it is likely to shed more light on this question.

Appendix: Inventory of Hebrew consonants

	Bilabial	Labio-dental	Alveolar	Palato-alveolar	Palatal	Velar	Uvular	Glottal
Plosives	p b		t d			k g		ʔ
Affricates			¢	č ǰ				
Fricatives		f v	s z	ʃ ʒ			χ	h
Nasals	m		n					
Liquids			l				ʁ	
Glides					j			

(¢=ts; č=tʃ; ǰ=dʒ)

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