The development of the speech production mechanism in young children : evidence from the acquisition of onset clusters in Dutch

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Title: The development of the speech production mechanism in young children : evidence from the acquisition of onset clusters in Dutch
Date: 2017-10-31

Chapter 4. Two-year-olds' cluster productions in naming tasks

4.1. Introduction

In Chapter 2 the realization of target words starting with /Cr/ and/ kn/ clusters was studied, and it turned out that an acoustic trace of the omitted segment was present. Chapter 3 focused on the longitudinal spontaneous realization of target words starting with a /Cr/ cluster and a developmental pattern in the realization of these words was found, where the presence of an acoustic trace occurred in a specific developmental stage, preceded by a stage where no acoustic trace was present.

Up until now the data that were analyzed were mostly spontaneous utterances. In this chapter I report on a more experimental approach to longitudinal cluster production, the goal of which is to locate in a more controlled way the problematic levels of processing in the model and to get insight into the development of the production mechanism. In Chapter 1, the possible effects that malfunctioning/absent modules in the model of speech production may have on children's spontaneous word productions were discussed. Here I use the model to make predictions about the performance on different types of production tasks. The idea is that the performance on different types of production tasks, namely picture naming, word repetition and nonword repetition, can tell us something about the functioning of the different modules in the production mechanism. In a similar way, Den Ouden (2002) compared the performance of aphasic patients on production tasks. There too, the ultimate goal was to detect the layer in the speech production mechanism of each patient at which problems occurred that caused phonological errors. Since Den Ouden's study is one of the small number of studies in which the Levelt et al. (1999) production model is used to study a speech system deviating from the norm, and since child language data also show deviations from the norm, a similar study with two-year-olds was planned.

For the present study, the tasks used by Den Ouden were adapted to become suitable for two-year-old children. In addition, the production tasks were administered several times over a longer period of time in order to see whether changes occurred that could point to developmental changes in the production mechanism. The intention was to also include a longitudinal perception task, which would be able to tell us about the individual development of the lexical representation of the onset clusters of target words. However, due to problems with the design of the study, it turned out to be impossible to interpret the results of these experiments in a meaningful way. Unfortunately one source of information is therefore missing. The remainder of this chapter is organized as follows: In 4.2 I discuss the theoretical background of the present work and explain what performance on the different tasks can tell us about the developmental state of the production mechanism. In 4.3 the materials and methods of the different tasks are presented. In 4.4 the results of the individual children will be discussed in detail. A general discussion and conclusions are presented in 4.5.

4.2. Background

According to Kohn and Goodglass (1985), phonological errors of patients with aphasia could be the result of damage that causes problems either with lexical access, or with access to the functioning of phonological encoding, phonetic encoding or articulation. Following up on this idea, Den Ouden (2002) designed an experiment that aimed to trace the source of the segmental problems of patients with aphasia to lexical access, phonological encoding or phonetic encoding. He did not focus on the level of articulation because when problems occur at this level, it results in a particular kind of aphasic disorder, namely dysarthria of speech. Den Ouden designed three tasks, picture naming (PN), word repetition (WR) and a phoneme detection task (PERC), and explained in what way the scores on these tasks could be used to identify the functional locus of the impairment in the Levelt et al. (1999) speech production model. According to Den Ouden, deficits at a particular level result in a specific performance pattern in these tasks: if the impairment lies at the level of lexical access, patients will perform better on word repetition than on phoneme detection and picture naming, while performance will be poor on all three tasks if the functional locus of the impairment is at the phonological encoding level. Impairment at the level of phonetic encoding causes poor performance on the picture naming and repetition tasks, while phoneme detection should not be affected. This will be discussed in more detail below (4.1.2). I now first turn to some production studies with young children that have been performed previously, and are relevant to the present study.

4.2.1. Young children's performance on production tasks

In the literature, extensive attention has been paid to how children in different age groups perform on production tasks. Numerous acquisition studies have focused on the differences between naming and repetition tasks (Hoff et al., 2008; Zamuner, 2009; Munson et al., 2005), or differences between nonword repetition (NWR) and other measures of productive vocabulary (Metsala, 1999; Bowey 2001; Paradis, 2011). However, the focus of these studies was different from the focus of the present study, and either lay on the relation between phonological memory, as represented by the performance on a NWR task, and vocabulary size, or on the relation between phonotactic probability and production success. The most relevant studies for this chapter are the ones by Vance et al. (2005), Hoff et al. (2008) and Zamuner (2009).

The main goal of the study of Vance et al. (2005) was to test the speech production model by Stackhouse and Wells (1997), a model very similar to that of Levelt et al. (1999). In order to find out which part of the model is affected when children of different age groups make speech errors, PN, NWR and WR tasks are carried out with English-speaking children between 3 and 7 years of age, and for each age-group their performance on the three tasks was compared. Their responses were scored as being either correct or incorrect. For the 3-year-olds performed worse on the PN task than on the two repetition tasks, while the 4-year-olds performed worse on the PN and the NWR tasks as compared to their performance on the WR task. Not surprisingly, the older the children were, the better their performance on the PN task became. The authors interpreted the poor performance on the PN task by 3-year-olds, as resulting from problems retrieving the words from the mental lexicon. They performed better on the repetition tasks because they were aided by the presence of the adult model. In the 4-year-olds, some immaturity of the lexical representation still affected the performance on the PN task, which was worse than their performance on the WR task. In the performance of the 5-year-olds, the difference between WR and PN had disappeared, while they continued being less accurate on the NWR task, just like the 6- and 7-year-olds. The authors suggest that for the oldest age groups there is a beneficial effect of the lexical representation on speech output processing. It appears that the speech processing requirements of discriminating all the phonemes of the nonword, without top-down support of the mental lexicon, and with the additional task of creating a new motor program, negatively affect the performance on the NWR task.

Since the children studied in this thesis are around two-years old, the study by Hoff et al. (2008) is relevant. Here, two groups of English-speaking children, 20- and 24-month-olds, were tested. These children's real word and nonword repetitions were assessed, together with their productive vocabulary. The PCC (percent consonant correct) was calculated for the children's productions. According to this measure, the percentage of correct consonants in a word is calculated (number of correct consonants / total number of consonants × 100, where a consonant that has been substituted or deleted obtains zero points, while a correct consonant obtains one point). The vocabulary size was measured with the MacArthur-Bates Communicative Development Inventory CDI.

The results in Hoff et al. (2008) showed that the 20-month-olds scored significantly worse on the NWR than on the WR task, and that performance on the NWR task and vocabulary size were strongly correlated. These results were replicated with the 24-month-olds. The authors of this study conclude that NWR-accuracy reflects phonological memory capacity and that this capacity is related to the level of vocabulary development of children.

In the study by Hoff et al. (2008) the nonwords were phonologically matched to the real words but they were not controlled for their phonotactic probability. Zamuner (2009) tested the production of nonwords of 28 and 31-month-old Dutch speaking children. The stimuli consisted of nonwords that varied in the degree of phonotactic probability (PP) of the consonants in onset or coda position. The nonwords either had an onset or a coda with a low phonotactic probability, or an onset or a coda with a high phonotactic probability. Zamuner controlled for the neighborhood density of the constructed stimuli and found out that there were more neighbors for the high probability nonwords and more neighbors for nonwords differing in segments in word-initial position. The responses were scored as correct, incorrect or as no response. The analyses were based on the proportion correct responses per nonword category (low PP onset, low PP coda, high PP onset, high PP coda).

The first main finding was that phonotactic probabilities influenced children's accuracy in the production of nonwords, both in word onsets and in word codas. Children produced nonwords with high phonotactic probability more accurately, independent of the position. The second finding of importance was that children's vocabulary size correlated with the accuracy of their production. More specifically, children with larger vocabularies were more accurate in the production of segments in word onset position. This effect was explained by the higher neighborhood density for lexical items contrasting in word onset position. If more lexical items contrast in word initial position, then phonological representations of this position should be more developed, according to Zamuner.

From these studies we can conclude that children as young as 20 months are able to perform on PN and (N)WR tasks. For this young age-group, performance on these tasks has up until now only been correlated with vocabulary size and phonological memory, but not with the developmental state of the speech production mechanism. We will now turn to this mechanism again, and discuss, along the lines of Den Ouden (2002), the expected performance on production and perception tasks of two-year olds, given the potential developmental problems with lexical access, phonological encoding or phonetic encoding.

4.2.2. The (developmental) state of the production mechanism and performance on different tasks

4.2.2.1. The level of lexical access

The mental lexicon of a two-year-old child is still under construction and it is likely that stored forms are not always completely or correctly specified. Evidence from experimental infant perception studies sometimes points to detailed phonetic representations, and sometimes to incomplete phonetic specifications, depending on the age of the infants and the position of the segment in the word (Fikkert, 1994; Levelt, 2012; Stager & Werker, 1997; Swingley, 2009; Trehub et al., 2007; Zamuner, 2009;). As discussed in Chapter 1, an incorrect representation is expected to lead to regular incorrect word productions, while an underspecified representation could lead to variable word productions. A child who has problems at this level is expected to have problems with the PN task. In a naming task, the speaker needs to consult his or her mental lexicon in order to find the stored form that goes with the depicted object. In case an incorrect form is stored, an incorrect form will be produced. In a repetition task the lexical representation is not necessarily activated, since the auditory form is provided. Performance on a WR task could thus be better than performance on a PN task when problems lie at the level of lexical access or the stored lexical representation. It is possible, however, that the child does activate the lexical representation of a known word during repetition, blurring the difference between the two tasks. However, this route seems to be blocked in the nonword repetition task, since in the case of nonword repetition, there is no existing word form stored in the mental lexicon. Although it has been shown that even nonwords can activate the lexicon through word-likeness (Swingley & Aslin, 2000; Zamuner, 2009), performance on this task is expected to be largely unaffected when the level of lexical access is the source of the deviating word productions. Finally, if the lexical storage is incorrect, or if lexical access is problematic for a child, it should be difficult to perceive subtle differences between words - like between the correct form [trɛin] for *trein* (train) and the simplified form [tɛin]. In other words, we expect poor performance on a young children's version of Den Ouden's phoneme perception task.[1] To summarize, good performance on the NWR task in combination with poor performance on the PN (and PERC) task(s) would point to problems at the level of lexical access. Performance on the WR task could either be comparable to performance on the NWR task or to performance on the PN task, depending on whether the lexical representation of the to-be-repeated form is activated are not. In short:

Lexical Access/Representation Problem:
NWR, WR >> PN, PERC
or
NWR >> PN, WR, PERC

The conclusion reached by Vance et al. (2005) for the performance of the 3- and 4-year-olds, namely that the better performance on repetition tasks than on the

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[1] Note that this task is not meant to test a child's general auditory perception abilities, but his/her linguistic perception abilities.

PN task entails a lexical retrieval problem, thus very closely resembles[2] the above reasoning of Den Ouden (2002) for a potential source of problems.

4.2.2.2. The level of phonological encoding

At the level of phonological encoding, the sounds of the activated lexical item are retrieved and syllabified. At this level, then, an underlying *segmental* representation is mapped onto a *phonological output* representation. In picture naming, after retrieving the lexical item from the lexicon, this item needs to pass through the phonological encoding module in order to be produced. In the case of repetition, the phonological encoding stage can either be skipped, when the lexicon is bypassed, or not, in case the lexical route is taken.

Problems at the level of phonological encoding are not expected to affect the performance on a perception task (Den Ouden, 2002). If a child has stored a target-like segmental representation in his or her mental lexicon, he or she should be able to perform well on a perception task, despite a deficit at the phonological encoding level.

To summarize, poor performance on the PN task(s) in combination with good performance on PERC tasks is expected when there are problems at the level of phonological encoding. NWR could be good, when phonological encoding is bypassed, and WR could again either go with PN (poor) or with NWR (good). In short:

Phonological encoding problem:

NWR, PERC >> PN, WR

or

NWR, WR, PERC >> PN

[2] There is no reference to Den Ouden (2002) in Vance et al. (2005).

In order to differentiate a lexical access problem from a phonological encoding problem, performance on the PERC task is crucial. If PERC goes with NWR, the problem source is phonological encoding, while if NWR is better than PERC, then the problem source is lexical access. Since there is no PERC test in Vance et al. (2005) to differentiate the two sources, their 3- and 4-year-olds could also have had problems at the phonological encoding level. Unfortunately, because of the case study nature of the experiment, the PERC task I used could not give meaningful results and was left out. Therefore I only collected meaningful data from the children's performance on the production tasks.

4.2.2.3. The level of phonetic encoding

During phonetic encoding, a motor program is constructed and the phonemic string is mapped to gestural commands. This also requires the awareness of language-specific allophonic details of each sound. When a string of sounds is repeated, the acoustic form is directly translated into a gestural score at this level (Browman & Goldstein, 1989; Boersma, 1998). If there are problems at the level of phonetic encoding, all production tasks will be affected. The PERC task will remain unaffected, for the same reasons as given above for the phonological encoding level. In short:

Phonetic encoding problem:
PERC >> PN, WR, NWR

4.2.2.4. The level of motor programing

Den Ouden does not discuss what the consequences for the model would be when we would find better performance on the PN task compared to performance on the WR task. Nijland and Maasen (2005) distinguish between imitation and spontaneous speech, where imitation is a synonym for both WR and NWR and spontaneous speech is a synonym for PN. They discuss the possible scenario that children might be able to produce known words in spontaneous speech while being unable to imitate them. According to the authors, this could arise, due to the fact that in spontaneous speech uttered words are “overlearned”, while during imitation, on-line contextual adaptation of the segments is required. Nijland & Maasen label this as a problem of motor programing since it specifically concerns the articulatory cohesion within a syllable. If the lexical route is taken in the WR task, then we would expect both PN and WR to outperform NWR. This resembles the situation of the 5-year-olds in the Vance et al. (2005) study. In short:

Motor programing problem:
PN >> WR, NWR
or
PN, WR >> NWR

To conclude this section, in a similar way as in Den Ouden (2002) I have described the different repercussions for the performance on PN, WR and NWR tasks, when a deficit at one of the three modules - lexical access, phonological encoding and phonetic encoding – is assumed.

4.3. Materials and methods

4.3.1. Participants

Six children participated in the longitudinal study, four girls and two boys. The data of two of the girls were not included in the study because one girl was bilingual and another girl consistently refused to participate in the nonword repetition task. The data presented here thus come from four monolingual Dutch children, two boys, Lars and Matteo, and two girls, Meike and Hannah. They completed all tasks in all sessions, but due to technical issues the recordings of Meike’s session 3 and Matteo’s session 2 were not stored properly and were therefore lost. Lars was recorded between the age of 1;7 and 2;7; Matteo was recorded between age 2;00 and 2;5; Meike was recorded between age 1;11 and 2;3 and Hannah was recorded between age 2;1 and 2;6.

Data collection for a child was terminated when at least one of the cluster types in which we were interested, /Cr/, /Cl/ or /sC/, was acquired. The recordings were carried out in the children's homes, usually in the living room, which was maintained as quiet as possible. All recordings were performed by myself.

4.3.2. Procedure

Each child was recorded in his or her home for at least five consecutive sessions. The children's utterances were recorded with a Microtrack II digital recorder and an external Microtrack II microphone. Each session was carried out as follows: first the PN task was conducted, using a powerpoint slide show on a laptop, followed by the WR task and the NWR (or viceversa), during which the laptop was closed.

4.3.3. Material

The words used in the PN and in the WR tasks were identical. The words used in the NWR task were based on the phonological form of the words in the real word tasks. See Table 1 for the list of words and nonwords used in the three production tasks. The stimuli were subdivided into stimuli containing the following cluster types: /Cr/; /fric+r/; /sC/; /s+fric/; /Cl/; /fric+l/; /tʋ/ and /kn/, where C in this chapter is used for a plosive.

In Figure 1 is an example of one of the pictures I used in the PN task. For the WR task, I produced the Dutch word myself and tried to elicit repetition by using the following phrases:

1. Zeg maar *trein*. (Say *train*.)
2. Kun jij *trein* zeggen? (Can you say *train*?)

Figure 1: A picture of a Dutch train, familiar to two-year-olds, used in the picture naming task.

Figure 2: Two objects which were new and therefore unknown to young children used (when necessary) in the nonword repetition task, which represent two microbes (giardia and e-coli), the size of a small teddy bear.

1: Words and nonwords used in the three production tasks (PN, WR and NWR tasks); Dutch orthography is used for the annotation.

Custer Types	Clusters	Words	Translation	Nonwords[3]
/Cr/	/dʀ/	draakje	dragon	droon
	/kʀ/	kraan/ kroon	faucet/ crown	kriep/ kraak
	/bʀ/	broek	trousers	braak
	/tʀ/	trein	train	traak
/fric+r/	/χʀ/	gras	grass	graak
	/fʀ/	fruit	fruit	friep
/sC/	/sp/	speeltuin	playground	spaam
	/sk/	skippybal	skippyball	skaam
/s+fric/	/sχ/	schaap/ schaar/ schoen	sheep/ scissors/ shoe	schaag
	/sʋ/	zwembad/ zwart	swimming pool/ black	zwiep
/sn/	/sn/	snoep	candy	snaak
/Cl/	/kl/	klok	clock	klot
	/bl/	bloem	flour	bliep
/fric+l/	/fl/	vlinder	butterfly	vloon
	/fl/	fles	bottle	flaak
	/χl/	glas	glass (cup)	gler
/tʋ/ /kn/	/tʋ/	twee	two	twot
	/kn/	knoop	button	knaak

[3] Some of the nonwords are low frequency, often old-fashioned real words that are unknown to the children in this sample.

For the NWR task, the child was first simply asked to repeat a specific nonword. However, in case this did not elicit any production from the child, an unknown object was shown to him or her (see Figure 2). This object was given a name, the nonword, and the child was asked to repeat this name (Hoff et al., 2008). The following elicitation phrase was used in this case:

> Kijk, dit is een *traas* Hoe heet hij (ook al weer)?
> (Look this is a *traas*, what is its name (again)?)

The list of real words used in the PN, the WR tasks and the nonwords used in the NWR task are presented in Table 1.

For this test I was specifically interested in the effect of the different production tasks on the children's performance on cluster production. The words and the non-words that were compared therefore had to have similar phonotactic probabilities. To this end I computed the diphone transitional probabilities of the words and the nonwords based on the CELEX corpus of the Dutch language. After computing the diphone transitional probabilities, an averaged log transitional probability was obtained (Adriaans, 2011). Words for the WR and the PN tasks were considered suitable stimuli when they fulfilled three requirements. First, the selected words had to be familiar to two-year-olds, secondly, they had to be easy to visualize and, finally, the words had to start with different types of onset clusters. The different requirements made it difficult to keep the transitional probabilities (TPs) identical for all real-word/non-word pairs of stimuli. In Appendix 5[4], the TPs of the 22 real words and the 19 nonwords are presented. The mean log TP of the real words is -1.23, ranging between -1.49 and -0.90. The word with the highest logarithmic transitional probability in our list of words (-0.90), is *vlinder* (butterfly); while

[4] In the cluster types /sʊ/ and /sχ/, the TP only of the first word in the list reported in Table 1 was taken into consideration.

the word with the lowest log TP is *snoep* (candy). The real words are part of the first 1000 words from the obligatory vocabulary for Dutch preschool children (Bacchini et al., 2005).

The low frequency words go together with a high log TP, while the high frequency words go together with low log TP. For instance the word *vlinder*, is low frequent and meanwhile is also characterized by higher log TP (taking into account its negativity). The word *snoep*, on the other hand has a high frequency and a low log TP.

For the nonwords in our stimuli set, the mean log TP was -1.22, ranging between -1.42 and -1.11, where the high log TP of the word *zwiep* is an indication that, if it were a word, *zwiep* would be a word of a low frequency, while *braak,* with its low log TP of -1.42 would be a highly frequent word. We carried out a paired sample t-test to compare the log TPs of the real words with those of the nonwords and found no significant difference between the two sets of words ($p > .1$).

4.4. Results

4.4.1. Quantitative analysis

The children's responses were first phonetically transcribed by an experienced transcriber and subsequently they were categorized either as containing a complex onset cluster or not. Since I was especially interested in the acquisition of onset clusters, the accuracy of the segments following the onset cluster was not scored. I therefore did not use measures like PCC, *percent consonant correct*, (Shriberg & Kwiatkowski, 1982) and the PCC-R, *percent consonant correct – revised*, (Shriberg et al. 1993; Shriberg, et al. 1997), where both deletions and substitutions are scored as errors. Here I consider a cluster to be acquired when a sequence of two consonants is realized. This means that a cluster produced with consonant substitution (disregarding whether the substituted

consonant is C1, C2 or both) also counts as a cluster that has been acquired[5]. In the general analysis presented here, I make a distinction between cluster omission and cluster reduction. Below in Figure 3 I present the percentages of reduced (CV) and complex (CCV) clusters per session, per task, per child.
The performance of the four children over time on the PN task is shown in Figure 3, where a graph of the percentages of reduced [CV] and complex [CCV] realizations of the target onset clusters are presented for all four children.[6] In general, the same picture emerges for the other tasks, with a slightly different timing.

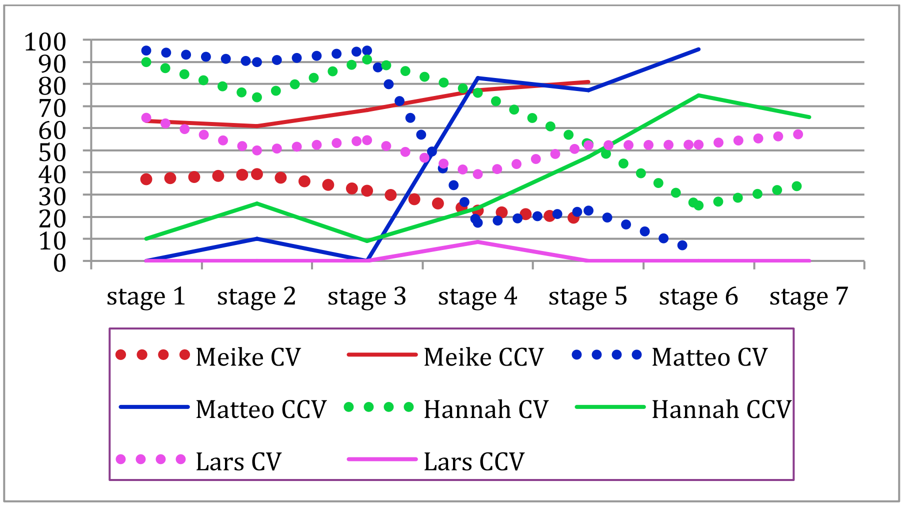

Figure 3: Percentage of the cluster realizations as /CV/ utterances (dotted line) and /CCV/ utterances (straight line) in the Picture Naming task by the four children.

[6] See Appendixes I to IV for all transcriptions of the data of all four children.

The general picture that can be deduced from Figure 3 is, as expected, that the number of reduced [CV] realizations decreases over time, while the number of complex [CCV] realizations increases. For two children, Matteo and Hannah, there is a clear breakpoint – at stage (here session) 4 for Matteo, and at stage (session) 6 for Hannah – while for Meike this breakpoint seems to have occurred already at some point before the first recording session. Lars, finally, is not really making progress in his realizations of complex [CCV] in the PN task at all in the data collecting period.

Graphs based on the percentages of realized CCV utterances of the individual children in the different tasks are presented in Figures 4-8. Since Lars hardly showed any development from reduced CV to complex CCV, but did show a development from omitted ØV to reduced CV, in his graph below the CV realizations are depicted. Here we see that the children perform differently in the different tasks, and that initially the highest percentages of [CCV] (or CV for Lars) realizations are found in the NWR task. In the final recordings, performance on the different tasks is more or less equal. For Matteo, performance on the WR task is similar to the performance on the PN task, while for Hannah, in the course of development, performance on the WR task becomes similar to the performance on the NWR task. For Meike performance on PN and NWR shows a similar pattern, while the performance on WR lags behind for some time.

Lars exhibits low percentage of ØV but a high percentage of CV forms in the first sessions in the NWR task. Overall, the word tasks show poorer performance in the first sessions (more ØV forms) and better performance in the final sessions (more CV forms). In the final session all tasks show an occurrence of ØV forms of around 45% and an occurrence of CV forms of around 55%.

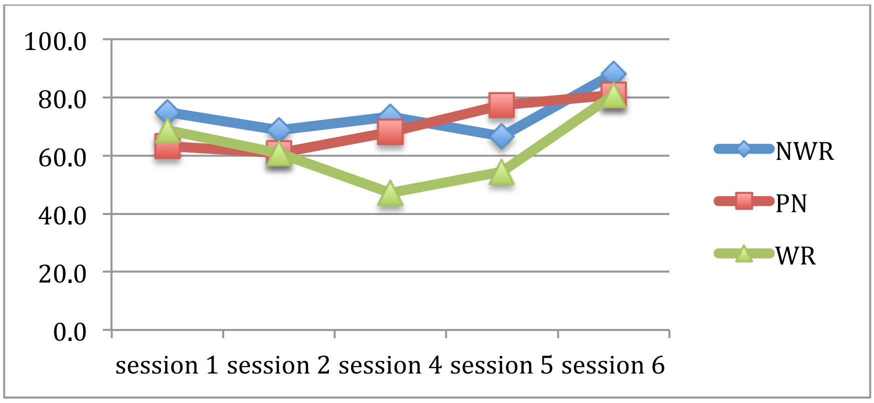

Figure 4: Percentage /CCV/ realizations in the NWR, PN, WR tasks for Meike.

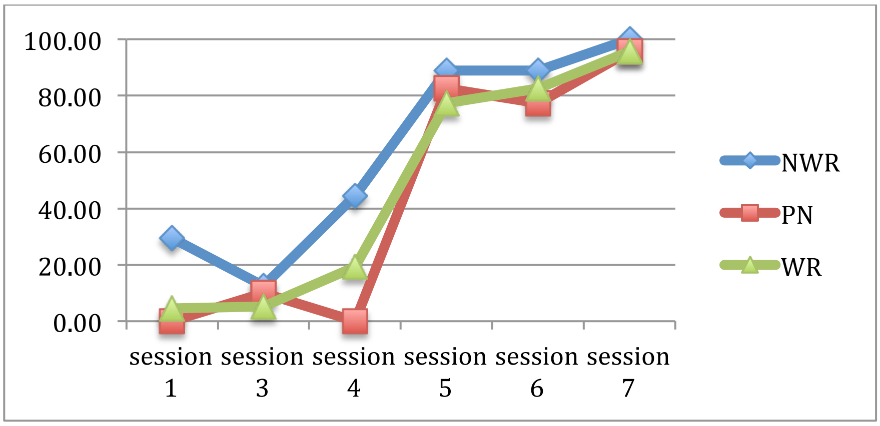

Figure 5: Percentage /CCV/ realizations in the NWR, PN, WR tasks for Matteo.

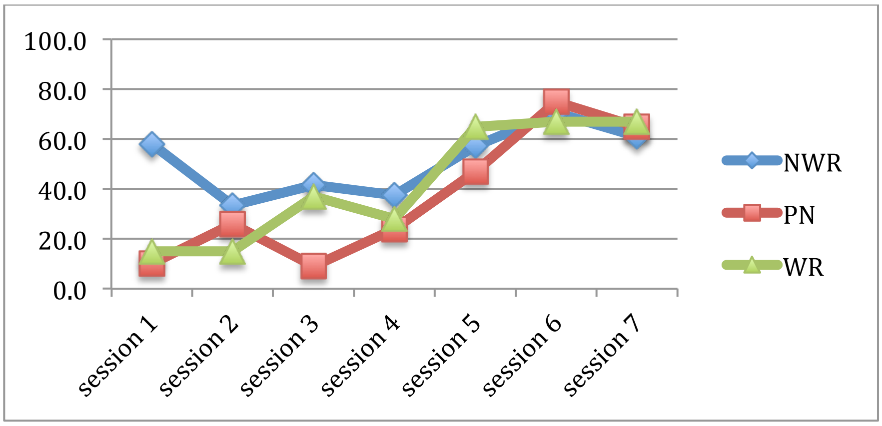

Figure 6: Percentage /CCV/ realizations in the NWR, PN, WR tasks for Hannah.

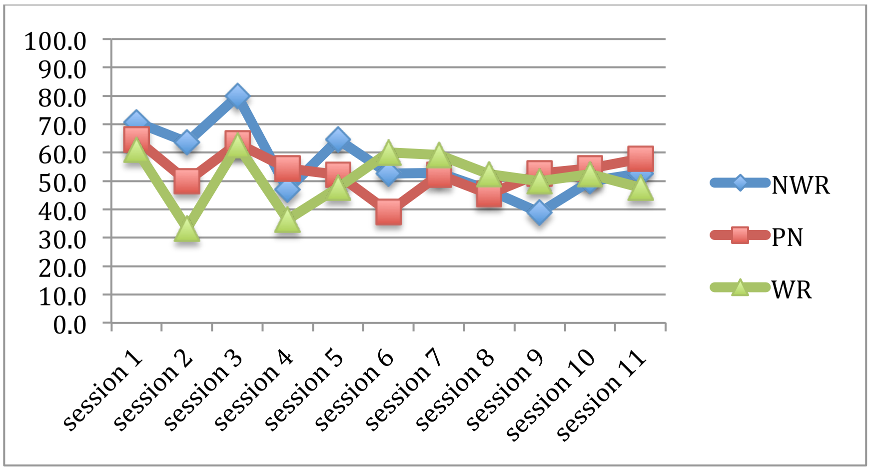

Figure 7: Percentage /CV/ realizations in the NWR, PN, WR tasks for Lars.

4.4.2. Intermediate summary

Two general patterns emerge from the data. The first salient pattern is that initially the highest percentages of cluster realizations (or singleton consonant realizations for Lars, see below) are found in the NWR task. The second general pattern is that in the final recordings, performance on the three different tasks is very similar. Except for Lars, performance on all tasks also shows a steady (Hannah, Matteo) or a more gradual improvement (Meike).

As explained in 4.2.2.1, if children score better on the NWR task than on the word task, then we can conclude that they have problems either with lexical access or with the lexical representation itself. In the case of NWR, the nonwords lack a representation in the mental lexicon, and this is why neither an incomplete lexical representation nor a phonological encoding problem could negatively affect the production of NWR items. Only real word productions, and real word repetitions in case the lexical route is taken, can be negatively affected.

Another finding is that some children appear to take the lexical route in the WR task, and therefore show similar performance on the WR and PN tasks (Matteo), while others (Hannah, Lars) appear to take the non-lexical route in the WR task, and perform in a similar way on the NWR and WR tasks. For Meike neither route can explain her results, since performance on the PN and NWR tasks is similar, while WR exhibits the poorest performance. In the discussion I will try to come up with an explanation for her poor performance on the WR task.

I will now turn to the results of the individual children, and discuss their performance on the different tasks and development in more detail.

4.4.3. Qualitative analysis

In the paragraphs to come I will offer an explorative analysis of the linguistic and psycholinguistic patterns found in the speech development of each individual child. The relatively small amounts of data within each session, within each production task and for each child preclude a statistical analysis. However, the results from our exploratory analysis do give an additional preliminary insight into the development of the speech production mechanism, and can be used to set up future research.

4.4.3.1. Case study Meike (1;11 - 2;3)

For Meike, the data of 5 recordings could be analyzed. She produces reduced versions of the cluster types /sC/, /kn/ and /zʋ/ in the first session, and still reduces /sk/, /sp/, /sx/ /zʋ/ in the final session. Production of the clusters /sl/, /sn/, /kn/ and /tʋ/ shows development over the sessions. For all Meike's productions see Appendix 1.

In Table 2 are the number of cluster realizations per session (raw numbers), the total number of productions (in parentheses) and the percentage of cluster realizations in the NWR, WR and PN tasks.

Table 2: Cluster realizations by Meike in the different tasks

	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	12 (16) 75%	11 (16) 68.8%	11 (15) 73.3%	12 (18) 66.7%	15 (17) 88.2%
WR	11 (16) 68.8%	14 (23) 60.9%	8 (17) 47.1%	12 (22) 54.5%	17 (21) 81%
PN	12 (19) 63.2%	14 (23) 60.9%	15 (22) 68.2%	17 (22) 77.3%	17 (21) 81%

Three developmental stages can be discerned: a first stage formed by sessions 1 and 2, a second stage formed by sessions 4 and 5 and a third and final stage in the last session. In the first stage, the performance on the NWR task is better than on the two real word tasks (PN and WR). In the second stage, both PN and NWR show higher cluster realization scores than WR. Finally, in session 6, performance on all three tasks is similar, and the percentage of target-like cluster realizations is high, above 80%.

Compared to the general pattern described above in 4.4.2, the main difference is that the low scoring on the WR task compared to the other tasks in the second stage (sessions 4 and 5) makes it impossible to categorize Meike as either a lexical route-taker or a non-lexical route-taker in the WR task. However, if we look at the actual forms that are uttered in the WR, PN and NWR tasks in session 4, there are hardly any target clusters that are produced correctly in the PN or NWR task, but are reduced in the WR task – there is only one case where Meike performs better in both the NWR and the PN task (NWR *knaak* [kna:k], PN *knoopjes* [klo:pjəs], WR *knoopjes* [no:pjəs]) and two cases where PN is better than WR (PN *twee* [dve], WR *twee* [ve:] and PN *kroon* [kro:n], WR *kroon* [xo:n]). The words *knoopjes* and *kroon* were produced with a correct cluster in the previous – and following – sessions in the WR task, while the cluster in PN *twee* was reduced in the previous and following sessions. The apparent discrepancy between NWR and WR, or PN and WR in session 4 is thus not so obvious when we look at the actual productions. This is very different from the discrepancies between conditions in the other children's data. For example, in session 4 Matteo utters no forms with clusters at all in the PN task, compared to eight cluster productions in the NWR task. In Meike's session 5, however, there are four cases where performance on the PN task is better than on the WR task, all involving the sound /x/ - in /sx/ or /xr/ clusters. This could mean that Meike does not take the lexical route in the WR task, and that cluster production in the PN task is facilitated by the activation of the segmental representation of the word.

In general, Meike produces stable and segmentally correct clusters from the start for most of the Cr/Cl clusters in all tasks. All /sC/ clusters are problematic for Meike. Since /sC/ clusters violate the sonority sequencing principle for onsets when C is an obstruent – consonant sequences in the onset should have increasing sonority – it has been proposed that /s/ in these clusters occupies an "extra-syllabic position" (ESP, Kager & Zonneveld 1986). Obstruent-liquid clusters and /s/ + obstruent clusters thus have different syllabic representations. Fikkert (1994) has shown that children vary in the order in which they acquire these different cluster types: some children acquire obstruent-liquid clusters first, while others acquire the /s/+ obstruent clusters first. In principle, /s/+ sonorant clusters could receive either a complex onset representation, since they obey the sonority sequencing principle, or they could be grouped with the /s/ + obstruent clusters and receive an ESP representation. Children seem to vary in the way they group these /s/ + sonorant sequences, and they either acquire these sequences simultaneously with other fricative + sonorant clusters, or simultaneously with /s/ + obstruent clusters (Fikkert 1994). The fact that Meike has problems with all /sC/ clusters, while other fricative + liquid clusters are produced correctly shows that she groups /s/ + sonorant clusters with the /s/ + obstruent clusters. Syllabification takes place at the level of phonological encoding. It can thus be expected that as long as the "extra-syllabic-position" is not acquired, or not available, the /s/ cannot be syllabified, and will not receive a motor program. As a result the /s/ will not be produced. This would affect the production of /sC/ clusters in the PN task, but not necessarily in the repetition tasks. The first (correct) cluster productions of target /sC/-cluster words do indeed appear in the NWR and WR tasks. As soon as the ESP representation is available for phonological encoding of a sequence of consonants, this is expected to facilitate the production of /sC/ clusters in the PN task, but again the repetition tasks will not necessarily be positively affected; performance could now even be worse in the repetition tasks than in the PN task. This is what we appear to see with Meike's production of /sx/ clusters in session 5, described above. Performance on the NWR and WR tasks – if the non-lexical route is taken – thus seems to be unstable, unlike performance on the PN task. In this task, productions will systematically go wrong when the representation is incomplete or when phonological encoding is problematic, but there will be systematic improvement when developments have taken place at these levels.

4.4.3.2. Case study Matteo (2;0 - 2;5)

Matteo was recorded between the age of 2;0 and the age of 2;5, and 6 out of 7 recording sessions could be analyzed. Matteo produced reduced productions of all tested cluster types in the initial session, and had acquired all of them by the time of the final session.

In Table 3 are the number of cluster realizations per session (raw numbers), the total number of productions (in parentheses) and the percentage of cluster realizations in the NWR, WR and PN tasks, for Matteo.

Table 3: Cluster realizations by Matteo in the different tasks

	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	5(17) 29.4%	1(8) 12.5%	8(18) 44.4%	16(18) 88.9%	16(18) 88.9%	19(19) 100%
WR	1(22) 4.5%	1(19) 5.3%	5(21) 23.8%	17(22) 77.3%	19(23) 82.6%	22(23) 95.7%
PN	0(21) 0%	2(20) 10%	0(21) 0%	19(23) 82.6%	17(22) 77.3%	22(23) 95.7%

There appear to be three developmental stages, formed by sessions 1-4, 5-6, and 7. In sessions 1-4 the performance on both the PN and WR tasks is very low, in sessions 5-6 there is a break-through and performance is suddenly high on all tasks, and in session 7 performance is almost at ceiling. Throughout the sessions, the number of cluster realizations is remarkably high in the NWR task (with exception of session 3). In 9 out of 19 cases where items are produced in all three tasks, the first cluster production occurred in the NWR task – in 9 cases the cluster appeared in all three tasks in the same session and in 1 case (*kraan*) a cluster production appeared in the WR task first. The largest difference between PN and NWR is in session 4. Performance on WR goes with the performance on PN, which suggests that Matteo takes the lexical route in the WR task.

For Meike a clear difference in development between /sC/ clusters and other clusters was found. This is less clear in Matteo's case, where all clusters seem to show up in the PN task at the same time, in session 5. However, target /sC/ clusters are the first to receive – usually incorrect – cluster productions in the NWR task. As mentioned above, it is actually not expected that the different phonological representations, ESP position versus complex onset, will play a role in repetition tasks like NWR. For Matteo, then, the initial /s/ could have acoustically highlighted the fact that a sequence of consonants should be produced. The fact that target /sp/ is the first cluster to be produced in a stable and correct way in the PN task, from session 3 on, could mean that this sensitivity, in turn, caused the early development of ESP processing during phonological encoding for Matteo. I will come back to this in the discussion.

4.4.3.3. Case study Hannah (2;1-2;6)

Hannah was recorded for 7 sessions between the age of 2;1 and 2;6, and all sessions could be analyzed. Except for the target clusters /xl/ and /sl/, she reduced all cluster types in the first recording session, and still reduced almost all /Cr/ clusters in the final session.

In Table 4 are the number of cluster realizations per session (raw numbers), the total number of productions (in parentheses) and the percentage of cluster realizations in the NWR, WR and PN tasks, for Hannah.

Table 4: Cluster realizations by Hannah in the different tasks

	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	11(19) 57.9%	5(15) 33.3%	5(12) 41.7%	6(16) 37.5%	8(14) 57.1%	12(17) 70.6%	11(18) 61.1%
WR	3(20) 15%	3(20) 15%	5(13) 37%	5(18) 28%	13(20) 60%	14(21) 67%	14(21) 67%
PN	2(21) 10%	5(19) 26%	2(22) 9%	4(17) 24%	9(19) 47%	15(23) 65%	15(23) 65%

Three developmental stages can be discerned, one formed by sessions 1-2, one by session 3-5 and one by sessions 6+7. The first 4 sessions are similar in the sense that performance is best on the NWR task and worst in the PN. In 11 out of the 16 cases where targets are produced in all three tasks, the first cluster production, correct or incorrect, occurred in the NWR task. In 5 out of 11 cases where the cluster was eventually produced correctly this occurred in the NWR task first, in 5 cases the correct cluster occurred in all tasks at once, and in 1 case it occurred in the WR task first. Thus, like in the cases of Meike and Matteo, the NWR task exhibits the most adult-like cluster realizations. In session 3, performance on the WR task becomes much better, and performance on WR and NWR outranks performance on PN. In the final two sessions performance is similar in all three tasks.

Cluster productions of target /s/+ obstruent clusters appear somewhat later than cluster productions of C+liquid clusters. All target /s/ + obstruent clusters are produced [st] in the final session. Target /sl/ goes with the other /Cl/ target clusters and appears (correctly produced) early. Target /sn/ goes with the target /s/+ obstruent clusters, but is produced correctly in the PN task from session 5 on. It thus appears that the ESP is acquired somewhat later than the complex onset, affecting the PN and WR tasks, but not the NWR task, where early – incorrect – clusters are produced for target /sC/ clusters.

4.4.3.4. Case study Lars (1;8-2;7)

For Lars 11 recording sessions are available, between the age of 1;8 and the age of 2;7, and all sessions could be analyzed. The data from all sessions are presented in Appendix 4. Lars has a different developmental pattern from the other children. While he reduced target clusters starting with a plosive, and /s/ + plosive clusters to singleton plosive consonants, he omitted the entire cluster from his productions if the target cluster was a fricative + liquid cluster. The complete omission of these target clusters is related to the fact that he also omitted target singleton fricatives and target singleton liquids from his productions (zeep /zep/ *soap* becomes [ep], goed /xut/ *good* becomes [ut], rood /rot/ *red* becomes [ot] for example). By the end of the recording period he still does not produce any consonant cluster spontaneously, and there are only a handful of instances where he produces a cluster in a repetition task.[7] Table 5 shows the number of cluster realizations, while Tables 6 and 7 show the number of singleton consonant realizations for target clusters starting with a plosive or with sP (Table 6), and for target clusters starting with a fricative and other s-clusters (Table 7), again per session (raw numbers), the total number of productions (in parentheses) and the percentage in the NWR, WR and PN tasks. Target cluster words that are not realized with a singleton consonant are, with only a few exceptions that are indicated, produced with completely omitted clusters.

[7] Lars started producing all consonant clusters in kindergarten and is fine now.

Table 5: Number of /CCV/ realizations per session

	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6
NWR	0(17) 0%	1(11) 9.1%	0(5) 0%	0(17) 0%	0(17) 0%	1(19) 5.3%
WR	0(18) 0%	0(14) 0%	0(8) 0%	2(22) 9.1%	0(21) 0%	0(5) 0%
PN	0(17) 0%	0(3) 0%	1(19) 5.3%	0(22) 0%	0(23) 0%	2(23) 8.7%

	Sess7	Sess8	Sess9	Sess10	Sess11
NWR	2(17) 11.8%	0(15) 0%	0(18) 0%	1(18) 5.6%	0(19) 0%
WR	0(22) 0%	0(21) 0%	0(22) 0%	1(21) 4.8%	1(21) 4.8%
PN	0(23) 0%	0(22) 0%	0(19) 0%	1(22) 4.5%	0(19) 0%

Table 6: Number of /CV/ realizations for plosive-initial and sP target clusters

	Sess1	Sess2	Sess3	Sess4	Sess5
NWR	9(9) 100%	6(6) 100%	3(3) 100%	8(8) 100%	9(9) 100%
WR	10(10) 100%	6(6) 100%	9(9) 100%	10(10) 100%	10(10) 100%
PN	9(9) 100%	1(1) 100%	6(6) 100%	8(10) 80% *	10(10) 100%

	Sess7	Sess8	Sess9	Sess10	Sess11
NWR	7(8) 87.5%*	7(7) 100%	7(8) 87.5%	8(9) 88.8%*	9(10) 90%
WR	11(11) 100%	9(9) 100%	8(8) 100%	10(11) 90.9%*	10(10) 100%
PN	10(10) 100%	10(10) 100%	10(11) 9.9%	10(11) 90.9%	9(10) 90%

*there is 1 CCV realization in this session **there are 2 CCV realizations in this session

Table 7. Number of /CV/ realizations for fricative-initial clusters (except sP)

	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6
NWR	2(7) 28%	1(4) 25%*	1(2) 50%	0(9) 0%	2(9) 22.2%	1(10) 10%
WR	0(6) 0%	0(5) 0%	2(7) 28.5%*	0(8) 0%	0(9) 0%	1(9) 11.1%
PN	0(7) 0%	0(2) 0%	0(2) 0%	0(9) 0%	0(9) 0%	0(4) 0%*

	Sess7	Sess8	Sess9	Sess10	Sess11
NWR	2(9) 22,2%*	0(8) 0%	0(8) 0%	1(9) 11.1%	0(8) 0%
WR	0(8) 0%	0(8) 0%	0(9) 0%	1(7) 14.2%*	0(7) 0%
PN	1(9) 11.1%	0(8) 0%	1(9) 11.1%	0(7) 0%	1(18) 12.5%

*there is also 1 CCV realization in this session

Unlike the other children, Lars does not show any systematic development towards cluster production, as can be seen in the Tables 5-7. However, if anything, it is again clear that the more advanced productions show up in the repetition tasks, and predominantly in the NWR task. Because of the lack of development in general with respect to cluster production, in Lars' case we could not find any indication of a different development for sC and C+liquid clusters.

4.6. Discussion

Den Ouden (2002) tried to pinpoint the source of errors in aphasic speech. He did this by administering a series of tests to speakers with aphasia, Non-word Repetition, Word Repetition, Picture Naming and a perception test. The scores on the different tests together indicated where in the speech production model the error source was located for an individual speaker. The aim of the present study was to apply this method to pinpoint the source of errors in young children's speech. While the speech production mechanism of an aphasic speaker is – at some point – stable, the speech production mechanism of a child is under construction, and changes over time. Therefore, by following young speakers for a longer period of time, I hoped to find evidence for the way in which the speech production mechanism develops; a change in the relative ranking of performance on the different tasks can be taken to indicate maturation of one of the encoding modules, and in the end it is expected that performance is equally good on all tasks. The focus of the present study lay on onset clusters, since these are error-prone in young children, and show a gradual development.

With respect to performance on the different tasks over time, there is indeed a developmental shift (except in the case of Lars), from an initial state where performance on NWR outranks performance on both WR and PN, to a final state where performance on all tasks is similar, and has improved, in the final sessions. In terms of Den Ouden (2002), then, in the initial state the problem lies either with lexical access or with the lexical representation, or with phonological encoding. Due to the fact that perception data are lacking, I cannot distinguish between these two possibilities. The non-lexical route through the speech production system is initially more successful than the lexical route, and performance on the WR task depends on the route that is taken in this task. The intermediate stage of Meike, where PN outranks both repetition tasks, shows that as soon as problems with lexical access/the lexical representation or phonological encoding are solved, the lexical route can actually boost performance because it quickly leads the speaker to the 'learned' motor program that is associated with the representation. Repetition requires constructing a new motor program, which might lead to errors. This is why performance on repetition tasks can be more successful initially, when difficulties with lexical access, struggling with an underspecified representation, or poor execution at the level of phonological encoding can be avoided, but less successful at later stages.

While the information on the children's performance on a perception task, which could be used to differentiate between a lexical access problem or a phonological encoding problem, is missing, the different performance on target /sC/ clusters and target C+liq clusters by three of the four children might help to pinpoint the error locus a little further (see 4.2.2 for the concrete predictions). As discussed above, /sC/ clusters are phonologically different from /C/ + liquid clusters in that /s/ occupies a specific prosodic position, namely the extra-syllabic position (ESP: Kager & Zonneveld, 1986; Fikkert, 1994). The two cluster types show a different timing in development, whereby target /sC/ clusters are produced correctly either later (usually) or earlier than target C + liquid clusters. This seems to imply a difference in processing at the phonological encoding level, rather than a difference in the way segmental information of these cluster types is stored in the mental lexicon: the ESP is either available for the phonological encoding of /s/ or not (yet), just like a complex onset is either available for the phonological encoding of consonants or not. Alternatively, if the absence of a prosodic position in the (developmental) phonological grammar would also affect the linguistic perception of segments in this position, then this could in turn affect the quality of the lexical representation. In this case it remains a problem to pinpoint the exact error locus. Moreover, in this case even a perception experiment would not be able to disambiguate the two possible error loci.

In the final recordings, performance at the PN task – and WR task in case the lexical route is taken there - has improved, and now all three tasks show a similar, but not perfect, performance. It thus appears that the specific problems at the higher levels of lexical access or phonological encoding are solved; it could be the case, for example, that segments can at this point be encoded in syllables with a complex onset. Den Ouden (2002) hypothesizes that if there is a problem at the level of phonetic encoding, all production tasks are affected. Therefore, since performance is still not perfect, and all tasks are now similarly affected, it can be concluded that the main error locus has shifted to the level of phonetic encoding.

Lars exhibits poor performance on all tasks, and this would entail that in his case the problem lies at the level of phonetic encoding, too. This conclusion seems odd in the light of the above discussion of the other children's development. Lars' productions are clearly far more immature than those of the other children, yet the conclusion is that the error locus in his production mechanism is the same as the one for the other children, while this was actually seen as a development from an earlier stage. Two other observations lead me to conclude that in the case of Lars, the entire production mechanism is not functioning well – at least not with respect to the processing of consonant clusters. For one thing, his performance is similar on all tasks, but contrary to the performance of the other children in the final recordings, it is also extremely poor. Secondly, an advantage for the NWR task for target words with fricative-initial clusters (but not sP) is found, where in some cases he produces a single onset consonant instead of omitting the entire cluster. This shows that in addition to problems at the level of phonetic encoding, there are problems at the higher levels of the model, too.

Overall, earlier cluster realizations were found in the NWR task, and the first correct cluster realizations were usually found in this task too. At first sight this appears to be a surprising finding, given that in the study by Hoff et al. (2008), children of the same age usually scored worse on their NWR than on their WR tasks. Hoff et al. state that this suggests that phonological memory demands for the repetition of real words are lower than for repeating non-words. This, in turn, is because the presence of a representational system, like a segmental representation in the mental lexicon, boosts memory capacity by proving an encoding system for the things that need to be remembered. The different findings in the two studies might be related to the different topics of interest, namely in the overall accuracy, measured by PCC in the Hoff et al. study, and in the cluster production ability in the present study. The overall accuracy was not taken into account in the present study, and this could have been lower for the non-words. However, in the study by Vance et al. (2005), where children between the ages of 3-7 years were tested on their performance on PN, WR and NWR tasks, the three-year-olds showed a higher percentage of correctly produced items in both the NWR and the WR repetition task than in the PN task, while the older age groups performed better in both the PN and the WR tasks than in the NWR task. For the three-year-olds the overall results on the WR task were slightly better than those for the NWR task – 66.67% (WR) vs 64.38% (NWR) – but this difference was not significant ($p = 0.289$). For one thing, this suggests that the three-year-olds in the Vance et al. study took the non-lexical route in the WR task, unifying WR and NWR results, while the older children took the lexical route, unifying WR and PN results. Two of the four children in the present study appeared to take the non-lexical route in the WR task as well, while for one the productions in the WR and the PN tasks were very similar, pointing to a lexical route for WR.

Interestingly, for the most complex condition in Vance et al., namely three-syllable words, the NWR had the highest score for the three-year-olds, 58.2%

NWR vs 56.7% WR. This is not a significant difference, but it shows a parallel with the present study, namely that the NWR condition appears to have an advantage in phonologically complex situations. A further parallel between the two studies lies in the fact that the non-lexical route leads to more advanced productions than the lexical route for the three-year-olds. Neither of these parallels can be drawn between the present study and the Hoff et al. study. With respect to phonological complexity, in their first experiment the stimuli in the WR and NWR tasks had the same number of syllables, but of the 9 NWR items 4 started with an onset cluster, compared to only 1 in the WR task – and these were different clusters. There is, thus, not a comparable complex condition in the WR and NWR tasks. In their second experiment they improved the comparability between the two stimuli sets, by replacing all the items with clusters by items with singleton consonants. Of the twelve items per condition, 3 contained three syllables, and performance on these stimuli could present the comparison. However, unfortunately performance on the individual items was not presented in the article, and because the three-syllable words only formed a small part of the total set of test items, differences that might have been there did obviously not survive in the overall performance. With respect to the lexical versus non-lexical route, there was no PN task in the Hoff et al. study, so it cannot be determined whether the participants in their study took the lexical or the non-lexical route in the WR task. In addition to the obvious difference between the small-scale longitudinal study presented here and the single-session, N=15 and N=21 studies of Hoff et al., the differences just discussed make it hard to compare the results of the two studies. The diverging results might thus be due to different underlying factors.

4.6. Conclusion

On the basis of the longitudinal study on the production of onset clusters, I concluded that for three of the four children, Meike, Matteo and Hannah, the initial difficulty in their speech production mechanism lay either in the lexical representation, which could be incomplete, or in the mapping between the phonological and the phonetic encoding level. This conclusion was drawn on the basis of the discrepancy in performance on the NWR and the PN tasks, where in the NWR task more advanced productions were encountered than in the PN task. In the course of time performance on the three tasks became more similar, and improved, indicating a shift in the main error locus from the lexical or phonological encoding level to the phonetic encoding level. In the case of Lars, severe problems with all tasks in addition to evidence for additional problems at the lexical or phonological encoding level led me to conclude that in his case it was impossible to determine exactly what the issues were..

The present study leads to new research questions that should be tested in a carefully set-up, larger study.

A first hypothesis concerns the relative success on production tasks requiring either the lexical route or the non-lexical route. The first adult-like cluster realizations are visible in the NWR task. This points to an initial production advantage for forms that lack a lexical representation over forms that probably have an incomplete or faulty representation in the mental lexicon. This advantage disappears as the segmental representations of real words become more complete and stable in the course of development. From then on, production benefits from this representation; performance on the PN task is no longer worse than performance on the NWR task, and for some children performance on this task even becomes better than the performance on the NWR task. The quality of segmental representations thus seems to be an important factor in the relative performance on production tasks that require taking the lexical route through the model and those that do not require this. As long as representations are unstable or incomplete, the young speaker can excel at repetition tasks, while a stable and complete representation can boost performance on real word tasks, by providing the segments to be produced, together with the established links between the segmental representation and a motor pattern. In the present study, the children's last sessions showed comparable scores on all three tasks. At this point the children had named or repeated the words and the nonwords several times already, and they could have developed motor programs for these words. The presence of a motor program entails that less contextual adaptation of the different phones is required, which facilitates speech production (Nijland & Maassen, 2005). This could have obscured differences between the three tasks in the final recording. This hypothesis about the relative performance on PN and (N)WR tasks and the role of the lexical representation should be studied by carefully balancing real words with and without well-established lexical representations, and systematically comparing the naming of these words to the repetition of similar non-words.

Another question that unfortunately could not be answered in the present study is whether the problem at the initial stages lies with lexical access/the lexical representation or with phonological encoding. This can only be disambiguated by probing the child's lexical representation, for which a well-designed perception experiment is needed (see 4.2.2 for the concrete predictions for a perception-production exmeriment). This is challenging, especially in a longitudinal study. Up until now perception studies with young children have always been group studies, while in this case one would need to compare an individual's performance on perception and production tasks. In addition, in a longitudinal study the challenge is to perform a series of different perception tasks, in order to avoid too much task-experience or boredom.

Appendix 1: Transcriptions of the words and nonwords in Meike's onset cluster development in three production tasks over time (1-19); transcriptions of real words used in the PN and the WR tasks (20 - 23).

1. /Cl/ words: the development of the nonword *bliep* and the word *bloem*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*bliep*	blip	blip	blip	blip	blɪp
PN	*bloem*	blumə	blum	plum	blumə	blum
WR	*bloem*	plum	blum	blumə	blumə	blum

2. /Cl/ words: the development of the nonword *klot* and the word *klok*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*klot*	kle:s	klɔk	klɔt	lɔt	klɔt
PN	*klok*	klɔk	klɔk	klɔk	klɔk	
WR	*klok*	lɔk	klɔk	klɔk	klɔk	klɔk

3. /Cr/ words: the development of the nonword *traak* and the word *trein*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*traak*	kra:s	kra:k	tra:k	tra:k	tra:k
PN	*trein*	trɛin	trɛin	trɛin	trɛm	trɛin
WR	*trein*	trɛin	trɛin	tərɛin	rɛin	trɛin

4. /Cr/ words: the development of the nonword *droon* and the word *draakje*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*droon*		dron	dro:n	dro:m	dro:n
PN	*draakje*	ra:kjə	xra:tjə	dra:k	dra:kjə	

WR	*draakje*	tra:kjə	dra:tjə	dra:kjə	dra:kjə	dra:kjə

5. /Cr/ words: the development of the nonword *kriep* and the word *kraan*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*kriep*	krɛs	krip	krip	kip	klip
PN	*kraan*	kra:n	krɛin	tra:n	kra:n	
WR	*kraan*	kra:n	krɛin		tra:m	kra:n

6. /Cr/ words: the development of the nonword *braak* and the word *broek*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*braak*	bra:s	bra:k	bra:k	bra:k	
PN	*broek*	brukjə	bruk	brukjə	bruk	
WR	*broek*		bruk		bruk	bruk

7. /fric+r/ words: the development of the nonword *friep* and the word *fruit.*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*friep*	frik	frip	fwip	frip	frip
PN	*fruit*	frœʏt	frœʏt	frœʏt	frœʏt	frœʏt
WR	*fruit*	prœʏt	frœʏt	frœʏt	frœʏt	frœʏt

8. /fric+r/ words: the development of the nonword *graak* and the word *gras.*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*graak*	xra:k	xra:	xra:k	xra:k	xra:k
PN	*gras*	xɑs	xrɑʦ	xrɑs	xrɑs	xrɑs
WR	*gras*	xrɑs	xɑs		xɑs	xrɑs

9. /kn/ words: the development of the nonword *knaak* and the word *knoopjes*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*knaak*	knɪk	kla:k	kna:k	xna:k	kna:k
PN	*knoop*	klo:pəs	klo:pjəs	klo:pjəs	kno:pjəs	kno:pjəs
WR	*knoopjes*	klo:pjes	klo:pjəs	no:pjəs	kno:pjəs	kno:pjəs

10. /s+fric/ word: the development of the nonword *schaag* and the word *schaap.*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*schaag*	xɑk	xa:x	xa:x	xa:x	xa:x
PN	*schaap*	xa:pjə	xa:p	xa:p	xra:p	
WR	*schaap*	xa:p	xa:p	xa:p	xa:p	

11. /sC/ words: the development of nonword *skaam* and the word *skippybal.*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*skaam*	ka:n	ka:m	ka:n	ka:n	ka:m
PN	*skippybal*	kɪpəbɑl	kɪpibɑl	kɪpibɑl	kipɪbɑl	kipɪbɑl
WR	*skippybal*		kɪpibɑl	pɪpibɑ	kipɪbɑl	kipɪbɑl

12. /sC/ words: the development of nonword *spaam* and the word *speeltuin.*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*spaam*	pa:s	pa:n		pa:n	spa:m
PN	*speeltuin*	pe:lətœʏn	pe:lpɛin	pe:ltœʏn	pe:ltœʏn	pe:ltœʏn
WR	*speeltuin*	pe:tœʏn	pe:ltœʏn	be:ltœʏn	be:ltœʏn	pe:ltœʏn

13. /sn/ word: the development of nonword *snaak* and the word *snoep.*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*snaak*	se:k	sna:k	na:k	sna:k	sna:k
PN	*snoep*	sup	ʃupjsə	knupjəs	fnupjəs	snup
WR	*snoep*	tnup	sup			snup

14. /tv/ word: the development of nonword *twot* and the word *twee.*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*twot*				vɔt	tvɔt
PN	*twee*		ve:	dve:	ve:	fve:
WR	*twee*	tve:	fe:	ve:	ve:	fve:

15. /fric+l/ words: the development of nonword *gler* and the word *glas*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*gler*	xle:t	xɛpla	xəlɛr	xjɛl	klɛr
PN	*glas*	xlɑs	xlɑs	las	xlɑs	xlɑs
WR	*glas*	lɑs	xlɑs	xlɑs	klɑs	xlɑs

16. /fric+l/ words: the development of the nonword *vloon* and the word *vlinder*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*vloon*	fle:t	flo:n	flo:n	flo:n	flo:n
PN	*vlinder*		flɪnəɹ	flɪnər		
WR	*vlinder*		flɪŋər	flɪndər	flɪnə	flɪndər

17. /fric+l/ words: the development of the nonword *flaak* and the word *flesje*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*flaak*	flɑp	fla:k	la:k	fla:k	kla:k

PN	*fles*	flɛsjə	flɛsjə	flɛsjə	flɛsjə	
WR	*flesje*	lɛs	flɛsjə	flɛsjə	flɛsjə	flɛs

18. /fric+l/ words: the development of nonword *sloon* and the word *slingers.*

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*sloon*	plo:n			slo:n	flo:n
PN	*slingers*	siliŋə	tlɪŋərs	slɪŋəs	tlɪŋərs	slɪŋərs
WR	*slingers*		tlɪŋərs		slɪŋərs	slɪŋərs

19. /s+fric/ words: the development of the nonword *zwiep* and the word *zwart*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
NWR	*zwiep*					
PN	*zwart*	twɑrt	vɑrt		vɑt	
WR	*zwart*	zʊat	fɑrt		vɑt	vɑrt

20. /s+fric/ words: the development of the word *zwembad* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
PN	*zwembad*	sfɛmbɑt	fɛmbɑt	vɛmbɑt	vɛmbɑt	
WR	*zwembad*	pəpɑt	pɛmbɑt	vɛmbɑt	fɛmbɑt	

21. /Cr/ words: the development of the word *kroon* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
PN	*kroon*		xro:n	kro:n	kro:ntjə	
WR	*kroon*		kro:n	xo:n	kro:n	kro:n

22. /s+fric/ words: the development of the word *schaar* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
PN	*schaar*		xa:r		xra:rs	
WR	*schaar*		xa:r	xa:r	xa:r	

23. /s+fric/ words: the development of the word *schoen* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess4	Sess5	Sess6
PN	*schoen*	xun	xun	xun	xrɔn	
WR	*schoen*		xun	xun	xuns	xun

Appendix 2: Transcriptions of the words and nonwords in Matteo's onset cluster development in three production tasks over time (1-19); transcriptions of real words used in the PN and the WR tasks (20 - 23).

1. /Cl/ words: the development of the nonword *bliep* and the word *bloem*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*bliep*	pip	blip	blip	blip	blip	blip
PN	*bloem*	obumə	pum	bum	blumə	blumətʃə	blumə
WR	*bloem*	bum	bum	bumə	bumə	blumə	blumə

2. /Cl/ words: the development of the nonword *klot* and the word *klok*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*klot*	kɔp	kɔps	kɔk	klɔt	klɔt	klɔk
PN	*klok*		kɔk	kɔk	klɔk	klɔk	klɔk
WR	*klok*	kɔk	kɔk	kɔk	klɔk	klɔt	klɔk

3. /Cr/ words: the development of the nonword *braak* and the word *broek*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*braak*		ba:k	ba:k	bla:k	bra:k	bra:k
PN	*broek*	puk	buk	buk	bluk	bruk	bruk
WR	*broek*	buk	puk		bluk	bluk	bruk

4. /Cr/ words: the development of the nonword *kriep* and the word *kraan*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*kriep*	kɪp		kɪp	kəip	kɪp	krip
PN	*kraan*	ta:n	ka:n	ka:n	kla:n	kra:n	kra:n
WR	*kraan*	ta:n	ka:n	tla:n	kla:n	kro:n	kra:n

5. /Cr/ words: the development of the nonword *traak* and the word *trein*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*traak*	ka:k			tra:k	dra:k	tra:k
PN	*trein*		tεin	tεin	ʦεin	trεin	trεin
WR	*trein*	trεin	pεi	tεin	tlεin	trεin	trεin

6. /Cr/ words: the development of the nonword *droon* and the word *draak*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*droon*	bo:m		do:m	dlo:n	dlo:n	dro:n
PN	*draakje*	ta:tjə	ta:tjə	da:kjə	tla:k	da:kjə	dra:kjə
WR	*draakje*	ta:kjə	da:kjə	ta:kjə	tra:kjə	dla:kjə	dra:kjə

7. /fric+r/ words: the development of the nonword *friep* and the word *fruit*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*friep*	tip	fip	tlip	flip	flɪp	flip
PN	*fruit*	rœit	fœʏt	fœʏt	frœʏt		frawtə
WR	*fruit*	tœit	fœʏt	fœʏs	flœʏt	fwœʏt	frœʏt

8. /fric+r/ words: the development of the nonword *graak* and the word *gras*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*graak*	ka:k	ka:k	xra:k	xa:k	xla:k	xra:k
PN	*gras*	xɑʦ	xɑs	xɑs	xlɑs	xlɑs	xrɑs
WR	*gras*	kɑs		xrɑs		klɑs	xrɑs

9. /kn/ words: the development of the nonword *knaak* and the word *knoop*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*knaak*	kakok	ka:k	ka:	kla:k	kra:k	kna:k
PN	*knoop*	ko:pjəs	ko:p	ko:pjəs	klo:pjəs	klo:pjəs	kno:pjəs
WR	*knoopjes*	ko:pi	ko:pjə	o:kjəs	klo:pjəs	klo:pis	kno:pjəs

10. /s+fric/ words: the development of the nonword *schaag* and the word *schaap*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*schaag*	trax		xa:x	sxa:k	xla:x	sxa:r
PN	*schaap*	ta:p		a:pjə	xa:p	xa:p	sxra:p
WR	*schaap*	ka:p	xa:p	xa:	xa:p	sxa:pjə	sxa:p

11. /sC/ words: the development of nonword *spaam* and the word *speeltuin*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*spaam*	əspa:m		spa:m	spam	spa:m	sfpa:m
PN	*speeltuin*	pɪtœin	spiltœʏn		spe:ltœʏn	spe:ltœʏn	pe:ltœʏn
WR	*speeltuin*	petœin	spe:ltœʏn	spe:ltœʏn	spe:ltœʏn	spe:ltœʏn	pe:ltœʏn

12. /sC/ words: the development of nonword *skaam* and the word *skippybal*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*skaam*	kra:n		ka:	ska:m	ska:m	ska:m
PN	*skippybal*	kɪkɪbɑl		kɪpibɑl	skipɪbɑl	skɪpibɑl	skɪpɪbɑl
WR	*skippybal*			hkɪpibɑl	kikɪbɑl	skɪpibɑl	skɪpibɑl

13. /sn/ words: the development of the nonword *snaak* and the word *snoep*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*snaak*	ka:k		tfa:k	sla:k	sla:k	sna:k
PN	*snoep*	tupis		supjəs	supjəs	supjəs	snupjəs
WR	*snoep*	sup	sup	su:p	slup	sup	snup

14. /tv/ words: the development of the nonword *twot* and the word *twee*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*twot*		sɔpf	sɔt	tvɔt	tɔt	prɔt
PN	*twee*	te:	pe:	te:	tve:	tre:	tre:
WR	*twee*	te:	pe:	pɛ:	tve:	tve:	tve:

15. /fric+l/ words: the development of the nonword *gler* and the word *glas*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*gler*	sɛr	xrə	xlə	klɛm	xlɛr	xlɛl
PN	*glas*	aʃjə	χɑ:s	xa:	klɑs	xlɑs	xlɑs
WR	*glas*	kɑs		khɑs	klɑ	xlɑs	klɑs

16. /fric+l/ words: the development of the nonword *floon* and the word *vlinder*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*floon*	fo:m	fo:n	fwo:m	flo:n	flo:n	flo:n
PN	*vlinder*	tɪn:	sɪn:ə	fɪndəɹ	fɪn:əɹ	flɪnə	
WR	*vlinder*	fɪnə	sɪndəɹ	fɪnə	flɪnən	xlɪndəɹ	flɪndər

17. /fric+l/ words: the development of the nonword *flaak* and the word *fles*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*flaak*	ka:t		fa:k	fla:k	fla:k	fla:k
PN	*fles*		fɛs	fɛs	flɛs	flɛs	flɛs
WR	*fles*		fɛsjə	fɛsjə	flɛʃjə	flɛsjə	flɛsjə

18. /fric+l/ words: the development of the nonword *sloon* and the word *slingers*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*sloon*	xowom		so:n	slo:m	slo:k	slo:m
PN	*slingers*	tɪnəs	slɪn:ə	sɪn:əs	slɪndəs	slɪnəs	slɪnəs
WR	*slingers*	tɪtəs		sɪn:əs	slɪn:əs	slɪ:əs	slɪndəs

19. /s+fric/ words: the development of the nonword *zwiep* and the word *zwart*.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*zwiep*	plip					zʊip
PN	*zwart*	tɑs	sɑt	səɑ:t	zwɑt	zwɑt	zʊɑrt
WR	*zwart*	sɑt	sɑt	nɑt	zʊɑʦ	vɑt	zʊɑt

20. /fric+v/ words: the development of the word *zwembad* in the WR and the PN tasks.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
PN	*zwembad*	pɛmtɑt	sɛmbɑt	sɛm:ɑt	stsɛmbɑt	sɛmbɑt	zʊɛmbɑt
WR	*zwembad*	sɛmbɑt	sɛm:ɑt	sɛm:ɑt	sɛmbɑt	slɛmbɑt	sʊɛmbɑt

21. /Cr/ words: the development of the word *kroon* in the WR and the PN tasks.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
PN	*kroon*	ko:m	ko:ntjə		klo:m	kro:n	kro:n
WR	*kroon*	xo:n	ko:m	klo:n	kro:m	kro:n	kro:n

22. /s+fric/ words: the development of the word *schoen* in the WR and the PN tasks.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
PN	*schoen*	ku:n	χunə	xun	xun	xun	sxun
WR	*schoen*	xun	xun	kun	kxun	sun	sxun

23. /s+fric/ words: the development of the word *schaar* in the WR and the PN tasks.

	words	Sess1	Sess3	Sess4	Sess5	Sess6	Sess7
PN	*schaar*	xa:r	xa:ɹ	xa:	sxa:t	sxa:r	sxa:t
WR	*schaar*		χa:ɹ	xa:r	fa:r	xa:r	sxa:r

Appendix 3: Transcriptions of the words and nonwords in Hannah's onset cluster development in three production tasks over time (1-19); transcriptions of real words used in the PN and the WR tasks (20 - 23).

1. /Cl/ words: the development of the nonword *bliep* and the word *bloem*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*bliep*	pip	klip	blip	kip		blip	blip
PN	*bloem*	bumə	pumətjə	bumətjə	blumə	pɔmətjəs	blumətjəs	blum
WR	*bloem*	bumə		bəlumə		blumə	blumə	blum

2. /Cl/ words: the development of the nonword *klot* and the word *klok*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*klot*	klɔs	klɔt	klɔt	klɔt	klɔt	klɔt	klɔt
PN	*klok*		tlɔt	klɔt	klɔt	klɔt	klɔt	klɔt
WR	*klok*	slɔt	klɔt	klɔt	klɔt		klɔt	klɔt

3. /Cr/ words: the development of the nonword *traak* and the word *trein*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*traak*	taːt	daːt	daːt	baːt	taːt	tæːt	dæːk
PN	*trein*	tɛin	tɛin	tɛitjə	tɛin	stɛin	tɛin	tɛin
WR	*trein*		tɛin	tɛin	tɛin	tɛin	tɛin	tɛin

4. /Cr/ words: the development of the nonword *droon* and the word *draak*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*droon*	toːn	doːn	doːn	doːn	doːn	doːn	doːn
PN	*draakje*	taːtjə		daːtjə	daːjə	daːx		daːk

WR	*draakje*	taːtjə	daːtjə	draːtjə		draːtə	daːtjə	daːtjə

5. /Cr/ words: the development of the nonword *kriep* and the word *kroon*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*kriep*	klaːt		klɪpɪp	pip	tip	dip	dip
PN	*kroon*	toːn	toːn	toːn		toːn		
WR	*kroon*	toːn	toːn					toːn

6. /Cr/ words: the development of the nonword *braak* and the word *broek*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*braak*	klaːt		baːt		daːt	daːt	daːt
PN	*broek*	putjə	put	put	buts	but	but	but
WR	*broek*	put	but		but	buts	but	bup

7. /fric+r/ words: the development of the nonword *friep* and the word *fruit*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*friep*	pip	pjip	pip		flip	fip	pɪp
PN	*fruit*	poeʏt	poeʏt	flœʏt	fœʏt		foeʏt	poeʏt
WR	*fruit*	poeʏt			foeʏt	foeʏt	foeʏt	poeʏt

8. /fric+r/ words: the development of the nonword *graak* and the word *gras*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*graak*	tlaːt		xarə	xraːk	xaːt	xəlaːt	xaːt
PN	*gras*	tɑs	xlɑs	xɑs		xɑs	xɑs	xlɑs
WR	*gras*		klɑs	xrɑs	glɑs	xɑs	xɑrs	xɑs

9. /kn/ words: the development of the nonword *knaak* and the word *knoop*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*knaak*	knaːt	taːk	taːt		tənaːt	kənaː	kna̽ːk
PN	*knoopjes*	poːmpjəs	poːntjəs	boːmpjəs	poːpjəs	tənoːpjəs	təloːpjəs	tənoːpjəs
WR	*knoopjes*	pompəs	poːmpjs		poːpjə	tənoːpjəs	tənoːpjəs	tənoːpjəs

10. /s+fric/ words: the development of the nonword *schaag* and the word *schoen*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*schaag*	tlaːx	taːx		saːx	staːn	staː	staːt
PN	*schaap*	paːpjə		paːpjə	paːpjə	staːp	staːp	staːp
WR	*schaap*		paːp	paːpjə	taːp	staːp	staːp	

11. /sC/ words: the development of nonword *skaam* and the word *skippybal*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*skaam*	taːm	kaːm		taːm		staːm	staːn
PN	*skippybal*	pitɪbɑl	pipɪbɑl	pipɪbɑl	papɛbɑl	pipɪbɑl	stitɪbɑl	tipɪbɑl
WR	*skippybal*	pipɪbɑl	pipɪbɑl	pipɪbɑl	pipɪbɑl	spipɪbɑl	stipɪbɑl	stibɑl

12. /sC/ words: the development of nonword *spaam* and the word *speeltuin*.

	words	Sess1	Sess2	Sess3	Sess4	Sess6	Sess7
NWR	*spaam*	spa̽ːn	paːm	spaːm	paːn	spaːm	paːm
PN	*speeltuin*		putoeʏn	peːltoeʏn	pitœʏn		speːltoeʏn
WR	*speeltuin*	peːn	peːltoeʏn		peːltœʏn	speːltoeʏn	speːltoeʏn

13. /sn/ words: the development of the nonword *snaak* and the word *snoep*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*snaak*	klaːt			braːt	snaːt	tnaːk	xnaːt
PN	*snoep*	pupjəs	pumpjəs	pupjəs	doːpjəs	snupjəs	snupjəs	snup
WR	*snoep*	pup		pumpjəs	stənup	snup	snup	snup

14. /tv/ words: the development of the nonword *twot* and the word *twee*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*twot*	pɔt	pɔt	vɔt	tlɔt	tɔt	tɔt	dvɔt
PN	*twee*	teː	teː	teː			tʊeː	teː
WR	*twee*	teː	teː	teː	teː	teː		tveː

15. /fric+l/ words: the development of the nonword *gler* and the word *glas*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6	Sess7
NWR	*gler*	glɛt	klɑp		plɛ	xlɛp	xəlɛr
PN	*glas*	xlɑs		xlɑs	xlɑs	xlɑs	xɑs
WR	*glas*	tlɑs	xlɑs	slɛs	xlɑs	xlɑs	xlɑs

16. /fric+l/ words: the development of the nonword *floon* and the word *vlinder*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*floon*	poːn		foːn	floːn	floːn	floːn	foːn
PN	*vlinder*	fɪnəɹ	pɪndər		slɪndər	flɪnətjə	flɪnər	pɪndə
WR	*vlinder*	pɪnə	fɪndər	pɪndər	flɪnɛr	flɪnə	flɪnər	pɪnə

17. /fric+l/ words: the development of the nonword *flaak* and the word *flesje*.

NWR	*flaak*	falabak	flaː		flaːk	flaːk	flaːt	flaːt
WR	*fles*	fɛs	pɛsjə	fɛsjə		flɛs	flɛs	flɛs
PN	*flesje*	pɛtjə	pɛsjə	flɛsjə		flɛsjə	flɛs	flɛs

18. /fric+l/ words: the development of the nonword *sloon* and the word *slingers*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*sloon*	kloːn	sloːn	tloːn	tloːn	sloːn		sloːn
PN	*slingers*	tlɪnəs	tlɪnə			slɪnəs	səlɪnə	slɪnəs
WR	*slingers*	tlɪndəs	klɪkjəs	klɪnəs	tlɪnəs	slɪnərs	sxlɪnəs	slɪnə

19. /s+fric/ words: the development of the nonword *zwiep* and the word *zwart*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*zwiep*	pip						
WR	*zwart*	fɑrt	pɑrt	pɑrt	bɑːt	pɑrt	zpɑt	
PN	*zwart*	pɑrt	fɑrt	pɑrt	pɑrt	pɑrt	zʊɑt	zʊɑt

20. /s+fric/ words: the development of the word *zwembad* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
WR	*zwembad*	pɛmpɑt	pɛmbɑt	pɛmbɑt	sɛmbɑt	sɛmbɑt	sɛmbɑt	stɛmbɑt
PN	*zwembad*	pɛmbɑt		pɛmbɑt	sɛmbɑt		sɛmbɑt	sɛmbɑt

21. /Cr/ words: the development of the word *kroon* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
WR	*kroon*	toːn	toːn					toːn
PN	*kroon*	toːn	toːn	toːn		toːn		

22. /s+fric/ words: the development of the word *schaar* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
WR	*schaar*	taːr	taːr	taːr		staːr	staːr	staːr
PN	*schaar*	taːr	tsaːr				staːr	staːr

23. /s+fric/ words: the development of the word *schoen* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
WR	*schoen*	tun	tun	tun	tunə	stun	stun	stun
PN	*schoen*	tunə	tunə	tunə	tunə		stun	stun

Appendix 4: Transcriptions of the words and nonwords in Lars' onset cluster development in three production tasks over time (1-19); transcriptions of real words used in the PN and the WR tasks (20 - 23).

1. /Cl/ words: the development of the nonword *bliep* and the word *bloem*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*bliep*	bits	bip			bif	bip	bipf
PN	*bloem*	bo			bum:	bun	bum	bumə
WR	*bloem*	bəl		bubu	bumə	bun		bumə

	words	Sess8	Sess9	Sess10	Sess11
NWR	*bliep*	bip	tɪp	blip	pis
PN	*bloem*	bumə	bum	bum	bum ma
WR	*bloem*	bumə	a bumə	bumə	pumə

2. /Cl/ words: the development of the nonword *klot* and the word *klok*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*klot*	pɔts		tɔts	dɔts	tɔts	tɔts	
PN	*klok*	dɔt		dɔt	dɔts	tɔts	dɔts	dɔts
WR	*klok*	tɔts			tɔts	dɔts		tɔts

	words	Sess8	Sess9	Sess10	Sess11
NWR	*klot*	tɔt	tɔts	tɔts	tɔts
PN	*klok*	tɔts	tɔts	tɔts	tɔɹts
WR	*klok*	tɔts	a tɔts	tɔts	tɔts

3. /Cr/ words: the development of the nonword *traak* and the word *trein*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*traak*	dado		taːts	baːt	taːts	taːts	taːt
PN	*trein*	tɛi	tɛi	tɛi	tɛi	tɛi	tʀɛin	tɛin
WR	*trein*	tɛi	tɛi	tɛit	tɛjə	tɛin		tɛin

	words	Sess8	Sess9	Sess10	Sess11
NWR	*traak*		taːts	taːs	taːts
PN	*trein*	tɛin		tɛin	tɛin
WR	*trein*	tɛin	tɛin	tɹɛin	tɛin

4. /Cr/ words: the development of the nonword *droon* and the word *draak*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*droon*	toːn	doːn	doːn	doːn	doːn	doːn	doːn
PN	*draakje*	taːtjə		daːtjə	daːjə	daːx		daːk
WR	*draakje*	taːtjə	daːtjə	draːtjə		draːtə	daːtjə	daːtjə

	words	Sess8	Sess9	Sess10	Sess11
NWR	*droon*			doːn	toːn
PN	*draakje*	taːɹt	taːtjə	taːts	
WR	*draakje*	taːtsə	daːtjə	taːtsjə	taːsjɛ

5. /Cr/ words: the development of the nonword *kriep* and the word *kroon*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*kriep*	tɪts			dip		pip	bit
PN	*kroon*	doː		toːn	taŋə	woːn	doːn	toːn
WR	*kroon*	toː			toːn	boːm		toːn

	words	Sess8	Sess9	Sess10	Sess11
NWR	*kriep*	bip	a pip	pip	pɪp
PN	*kroon*	toːn	toːn	toːn	toːn
WR	*kroon*	toːn	toːn	toːn	toːnɹ

6. /Cr/ words: the development of the nonword *braak* and the word *broek*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*braak*	bats	baːts		bae	taːts	taːts	taːts
PN	*broek*	buts	buts	buts	puts	buts	buts	buts
WR	*broek*			buts	buts	buts	buts	buts

	words	Sess8	Sess9	Sess10	Sess11
NWR	*braak*	taːts	taːts	taːts	paːɹts
PN	*broek*		buts	buts	puts
WR	*broek*	buts	buts	buts	

7. /fric+r/ words: the development of the nonword *friep* and the word *fruit*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*friep*	ɪp	ip		its	ɪf	ip	fip
PN	*fruit*	œʏt	œʏt	œʏt	œʏt	œʏt	œʏts	œʏt
WR	*fruit*		atʃ		œʏt	œʏts	œʏts	tœʏt

	words	Sess8	Sess9	Sess10	Sess11
NWR	*friep*	ip	ɪp	ip	ip
PN	*fruit*	œʏt	œʏt	kœʏ	œʏt
WR	*fruit*	œʏt	œʏt	œʏʃ	œʏt

8. /fric+r/ words: the development of the nonword *graak* and the word *gras*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*graak*	ats			aːts	dɑs	aːts	aːts
PN	*gras*	ɑs	ɑs	ɑs	ɑs	ɑs	ɑs	ɑs
WR	*gras*	ɑs		ɑs	ɑs	ɑs		ɑs

	words	Sess8	Sess9	Sess10	Sess11
NWR	*graak*	aːts	aːts	aːs	aːs
PN	*gras*	ɑs	ɑs		ɑs
WR	*gras*	ɑɹs	ɑs	ɑs	ɑɹs

9. /kn/ words: the development of the nonword *knaak* and the word *knoop*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*knaak*	taːts	kăːk		taːts	taːts	taːts	taːts
PN	*knoopjes*	butə		doːtjə	dotsjə	doːtʃə	toːtʃə	boːtʃə
WR	*knoopjes*	butə		doːtjə	dotsjə	doːtʃə	toːtʃə	boːtʃə

	words	Sess8	Sess9	Sess10	Sess11
NWR	*knaak*	taːts	taːts	taːs	taːts
PN	*knoopjes*	toːtʃəs	poːmptəs	poːtjəs	boːtəs
WR	*knoopjes*	toːtʃəs	poːmptəs	poːtjəs	boːtəs

10. /s+fric/ words: the development of the nonword *schaag* and the word *schoen*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*schaag*	aːp	aːp	doː	ae	asː	s aːs	aːts
PN	*schaap*		aːp		aːpf	aːp	s aːp	aːp
WR	*schaap*			aːp	aː	aːp		aːpf

	words	Sess8	Sess9	Sess10	Sess11
NWR	*schaag*	aːts	aːs	haː	aːs
PN	*schaap*	aːptʃə	aːtsə	aːp	
WR	*schaap*	aːp	baːptsə	ampsə	

11. /sC/ words: the development of nonword *skaam* and the word *skippybal*.

	Words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*skaam*	taːm			tan	daːn	taːm	taːn
PN	*skippybal*	pɪti	pɪpi bɑl	pɪpibɑl	pipi bɑlə	pipibɑl	spipibɑl	bipibɑl
WR	*skippybal*	pɪti		pɪpibɑl	bɪpibɑl	pipibɑl	pipibɑl	

	words	Sess8	Sess9	Sess10	Sess11
NWR	*skaam*	taːn	aːn	taːn	paːn
PN	*skippybal*	pipibɑl		pipibɑl	pipibɑl
WR	*skippybal*	pipibɑl	pipibɑl	bipibɑl	pipibɑl

12. /sC/ words: the development of nonword *spaam* and the word *speeltuin*.

	words	Sess1	Sess2	Sess3	Sess4	Sess6	Sess7
NWR	*spaam*	taːm	paː	baː	taːnː	paːn	taː
PN	*speeltuin*	m tœʏn	bu tœʏn	tutœʏn	titœʏ	deːtœʏn	atœʏn
WR	*speeltuin*	p tœʏn		butœʏ	idœʏn	tɛtœyn	

	words	Sess8	Sess9	Sess10	Sess11
NWR	*spaam*	paːn	paːn		paːn
PN	*speeltuin*	teːtœʏn	teːtœʏn	teːltœʏn	teːtœʏn
WR	*speeltuin*	teːtœʏn	a teːtœʏn	teltœʏn	teːtœʏn

13. /sn/ words: the development of the nonword *snaak* and the word *snoep*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*snaak*	taːts			ɑts	aŋ	aːts	aːhts
PN	*snoep*		ɪpi	dutjə	upjə	uftʃɛ	upjə	uptsə
WR	*snoep*	ɔp			ups	upf		ups

	words	Sess8	Sess9	Sess10	Sess11
NWR	*snaak*	aːts	aːts	aːs	aːts
PN	*snoep*	upjəs	upjəs	utjəs	ba utəɹs
WR	*snoep*		a up		

14. /tv/ words: the development of the nonword *twot* and the word *twee*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*twot*	dɑts	ɔs			tɔts	dɔts	
PN	*twee*				teː	tɛ	teː	teː
WR	*twee*				tse	ti		teː

	words	Sess8	Sess9	Sess10	Sess11
NWR	*twot*		tɔts	tɔts	tɔɹs
PN	*twee*		teː	tjeː	teː
WR	*twee*	teː	teː	teː	teː

15. /fric+l/ words: the development of the nonword *gler* and the word *glas*.

	words	Sess1	Sess2	Sess4	Sess5	Sess6	Sess7
NWR	*gler*	dɛr			eː		ehe
PN	*glas*	ɑs	ɑs	ɑs		ɑs	ɑs
WR	*glas*	ɑs			ɑs	ɑs	

	words	Sess8	Sess9	Sess10	Sess11
NWR	*gler*		ɛɹ	ɛɹ	ɛɹ
PN	*glas*	ɑs	ɑs	ɑs	ɑɹs
WR	*glas*	ɑs	a ɑs	ɑs	aɹs

16. /fric+l/ words: the development of the nonword *floon* and the word *vlinder*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*floon*		fwoː		oːn	oːn	oːn	dɔts
PN	*vlinder*			ɪː	ɪŋəh	ɪnːɛ	ɛnɛ	ɪnːɛ
WR	*vlinder*	ɪ	ɪ		ɪŋə	ɪnːə	ɛnə	ɪnːə

	words	Sess8	Sess9	Sess10	Sess11
NWR	*floon*	oːn	oːn	oːn	oːn
PN	*vlinder*	ɪnə	ɪndəɹ		ɪnəɹ
WR	*vlinder*	ɪnːə	ɪnə	ɪnə	inəɹ

17. /fric+l/ words: the development of the nonword *flaak* and the word *flesje*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*flaak*	ats		aːts	ats	ats	aːts	slaːk
PN	*fles*	ɛs	ɛs	flɛs	ɛs	ɛs	ɛs	
WR	*flesje*	ɛs			ɛsː	ɛs		ɛsɛ

	words	Sess8	Sess9	Sess10	Sess11
NWR	*flaak*	aːts	aːts	aːts	aːts
PN	*fles*	ɛs	ɛs	ɛs	ɛs
WR	*flesje*	esjə	ɛsɛ		ɛsɛ

18. /fric+l/ words: the development of the nonword *sloon* and the word *slingers*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*sloon*		loː		aŋ	hoːn	oːn	oːn
PN	*slingers*			ɪː	ɪntej	ɪŋə	ɛnɛ	ɛnə
WR	*slingers*				ɪndis	ɛnɪs		ɪnəɹ

	words	Sess8	Sess9	Sess10	Sess11
NWR	*sloon*	oːn	oːn	oːn	oːn
PN	*slingers*	ɪnəs	ɪnə	ənəs	
WR	*slingers*	ɪnəs	ɪnəs	ɪnəs	ɪnəs

19. /s+fric/ words: the development of the nonword *zwiep* and the word *zwart*.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
NWR	*zwiep*	ɪp			ɪp	ɪp	ɪp	ɪpf
WR	*zwart*	ɑts		dɑːt	ɑts	aɹt	ɑs	ɑts
PN	*zwart*	ɑts			ats	ɑts	ɑts	tɑts

	words	Sess8	Sess9	Sess10	Sess11
NWR	*zwiep*	ɪp	ɪp	ip	ɪp
PN	*zwart*	ɑts	ɑts	ɑɹts	ɑɹt

WR	*zwart*	ɑts	ɑts	ɑɹts	aɹt

20. /s+fric/ words: the development of the word *zwembad* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
WR	*zwembad*	m bɑts	bɑt	bɛbɑt	ɛ bɑts	bɑts	ɛbasː	ɛbɑts
PN	*zwembad*	bɑts			pɛmpɑt	ɛbɑt		bɑt

	words	Sess8	Sess9	Sess10	Sess11
PN	*zwembad*	ɛbɑts		ɛmbɑt	ɛmbɑt
WR	*zwembad*		a ɛmbɑt	ɛmbɑtə	ɛmpɑt

21. /Cr/ words: the development of the word *kroon* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
WR	*kroon*	doː		toːn	taŋə	woːn	doːn	toːn
PN	*kroon*	toː			toːn	boːm		toːn

	words	Sess8	Sess9	Sess10	Sess11
PN	*kroon*	toːn	toːn	toːn	toːn
WR	*kroon*	toːn	toːn	toːn	toːnɹ

22. /s+fric/ words: the development of the word *schaar* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
WR	*schaar*			aːr	ajə	aːɹ	aɹa	aːɹ
PN	*schaar*				aːɹ	aɹ		aːɹ

	words	Sess8	Sess9	Sess10	Sess11
PN	*schaar*	aːɹ		aːɹ	aːɹ
WR	*schaar*	aːɹ		aːɹ	aːɹ

23. /s+fric/ words: the development of the word *schoen* in the WR and the PN tasks.

	words	Sess1	Sess2	Sess3	Sess4	Sess5	Sess6	Sess7
WR	*schoen*	o	o		un	unː	un	un
PN	*schoen*	u		u	un			un

	words	Sess8	Sess9	Sess10	Sess11
PN	*schoen*	un	un	un	
WR	*schoen*	un	a un	un	un

Appendix 5: Words and nonwords used in the three production tasks (PN, WR and NWR) and their respective averaged log transitional probabilities; Dutch orthography is used for the annotation.

words	averaged log transitional probability	nonwords	averaged log transitional probability
draakje	-1.20	droon	-1.17
kroon	-1.15	krip	-1.28
kraan	-1.13	kraak	-1.15
broek	-1.14	braak	-1.11
trein	-1.21	traak	-1.20
gras	-1.14	graak	-1.16
fruit	-1.36	friep	-1.39
speeltuin	-1.34	spaam	-1.12
skippybal	-1.23	skaam	-1.21
schaap	-1.23	schaag	-1.24
schaar	-1.04		
schoen	-1.24		
zwembad	-1.18	zwiep	-1.42
zwart	-1.12		
snoep	-1.49	snaak	-1.28
klok	-1.23	klot	-1.18
bloem	-1.27	bliep	-1.19
vlinder	-0.90	vloon	-1.18
fles	-1.27	flaak	-1.27
glas	-1.26	gler	-1.22
twee	-1.46	twot	-1.21
knoop	-1.37	knaak	-1.21