Syllable type development in toddlers acquiring Dutch

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Abstract

Compiling syllable type inventories from children's spontaneous speech is all but straightforward: so far studies vary considerably in their methodologies and consequently the selection of the speech samples differs. This paper shows that different methodologies for selecting a speech sample lead to substantial differences in syllable inventories. Two main sources for this variation are explored: differences in size and content of the speech samples. Both factors influence the results significantly and this questions the comparability of previous study results. An empirical procedure to investigate syllable type development is proposed to overcome such methodological problems, and this procedure is implemented to provide an initial empirically sound assessment of the acquisition of syllable types in Dutch speaking toddlers.

1. Introduction

A syllable type inventory takes stock of the syllable types that occur in a particular language. That is, starting from a list of words that occur in the language, the types of syllables are inventoried. In the language acquisition literature, the aim of syllable inventory studies is to chart out the normal developmental path of the acquisition of syllables and to assess the variation in a population.

Two different types of syllable inventory studies exist: *frequency* studies and *order of emergence* studies. In frequency studies, the frequency of syllable types is counted. This type of inventory has been compiled for children from different language backgrounds, including English (Stoel-Gammon, 1987; Watson & Scukanec, 1997), Italian (Keren-Portnoy, Majorano, & Vihman, 2009), Spanish (Goldstein & Cintron, 2001). Contrary to frequency studies, emergence studies chart the order of emergence of the different syllable types, such as for Dutch (Fikkert, 1994; Levelt, Schiller, & Levelt, 2000) or German (Grijzenhout & Joppen-Hellwig, 2002).

In order to construct and compare syllable inventories, students of language acquisition typically rely on transcriptions of spontaneous speech recordings. These recordings are used to determine the frequency distribution of syllable types or the sequence in which various syllable types emerge. Usually, as a next step, an explanation is sought for the distribution or emergence of syllable types in terms of theoretical constructs such as markedness. The present study will pay attention to the compilation of the spontaneous speech samples and on to the procedure followed in establishing children's syllable inventories on the basis of these samples.

The first step in analyzing syllables in children's speech consists of selecting the relevant material for analysis. In this respect, studies differ as to the portions of the corpora that are considered relevant. In the literature various selection procedures have been proposed, which differ as to the inclusion of imitated words, the inclusion of different variants of the same word, and the like. In the first study reported in this paper, the effect of these various selection procedures on the eventual syllable inventories is measured. If there is indeed a significant effect in that depending on the procedure syllable inventories of different sizes are compiled, then this hampers the comparison of children across studies.

Not only the composition of a speech sample but also the amount of speech data in a sample has been shown to influence the outcome of an analysis. The effect of the amount of data has been shown for several language measures (Hutchins, Brannick, Bryant, & Silliman, 2005; Rowland, Fletcher, & Freundenthal, 2008; Schiller, Meyer, Baayen, & Levelt, 1996; Taelman, Durieux, & Gillis, 2005; Tomasello & Stahl, 2004). These researchers point out that there is a need for using controlled samples (e.g., samples of equal size) when working with spontaneous speech data. In the second study reported in this paper, it will be illustrated that depending on the amount of data in the speech samples, the composition of the syllable inventories varies considerably.

Having shown in Study 1 and 2 that differences in the procedures do indeed matter, a new procedure will be proposed which takes into account the identified methodological pitfalls. This new procedure will be applied in charting out the syllable inventories from transcriptions of the spontaneous speech of 30 children acquiring Dutch. As such, this constitutes the largest cohort studied in a longitudinal study of the developmental order of emergence of syllable types. The study reveals an invariant pattern that covers the development at word-onset, but over time this pattern becomes more and more variable. The results do not corroborate prior studies of syllable structure development in Dutch. Consequently, this questions the interchangeability of inventory studies' results as such. Particularly, comparative studies which involve clinical and typically developing populations should take into account the methodological issues discussed in this study.

2. Study 1: Comparison of different procedures

Researchers have applied variable guidelines for compiling syllable inventories. The purpose of the present study is to examine the effect of word and/or syllable selection criteria on the syllable inventories. Three procedures used in the literature were selected, namely those used by Stoel-Gammon (1987), Thal, Oroz, & McCaw (1995), and Levelt et al. (2000). These three procedures differ in the word / syllable selection criteria, and the aim is to find out if these differences really matter: does the application of the specific selection criteria lead to different syllable type inventories? If that is indeed the case, then this poses serious problems with respect to the comparability of the findings reported in the relevant literature up till now.

2.1. *Method*

2.1.1. *Participants, data collection and annotation*

Thirty typically developing, monolingual children (14 girls and 16 boys) acquiring Dutch and living in Flanders (the northern, Dutch-speaking part of Belgium) were (video) recorded longitudinally from 6 months until 24 months of age on a monthly basis. The infants were recruited by announcements posted at the university, in day-care centres, on a popular website for young parents (www.zappybaby.be), and from families known by the researchers. Children were included in the study population when they showed no health or developmental problems, no (history of) hearing problems were apparent, and no repeated scores less than percentile 1 on the N-CDI (Zink & Lejaegere, 2002) were achieved. Parents were also monolingual, had normal hearing, and spoke Standard Dutch to their child. Furthermore, they could be categorized as mid-to-high Socio Economic Status (mhSES) according to the selection criteria developed for the *Corpus Gesproken Nederlands* (CGN, the "Spoken Dutch Corpus").

2.1.2. *Data collection*

Video- and audio recordings of spontaneous speech of the 30 children were collected once a month from the age of 6 months onwards up to 24 months of age. Recordings took place at the children's homes and consisted of spontaneous, unstructured interactions between the children, their parent(s), and occasionally the researcher, a sibling or other family member(s). Recordings were made with a JVC digital camera (type GZ-MG77E) with built-in microphone. Every month 80-120 minutes of interaction per child were videotaped. After the recording session, the researcher selected twenty minutes in which the child was most vocally active.

2.1.3. *Data annotation*

Based on the visual and acoustic signal the twenty minutes sample of each recording was transcribed by means of the CLAN application according to the CHAT conventions (MacWhinney, 2000). A sample transcription and annotation is provided in (1).

(1) *CHI: tractor.

%eng: tractor

%pho: tatɔ

%syl: 1 t a ._0 t ɔ ./

%cva: 1 c v ._0 c v ./

The transcription in (1) contains one utterance of a child (*CHI). The identifier *CHI is followed by an orthographic transcription, and, for convenience sake, an English translation is added (%eng). The line headed by %pho contains the phonemic transcription in IPA symbols. The syllabified phonemic string is represented on the %syl line: syllables are identified and syllable boundaries are marked by the underscore character. Each syllable is further analyzed as consisting of an onset, a nucleus, and a coda. Unfilled positions are represented by a full stop character ".". For instance, the coda of the first and the second syllable in example (1) are empty. In addition, the lexical stress of each syllable is indicated: 1 = stressed, 0 = unstressed. On the %cva line, segmental information is represented as either C for consonants or V for vowels.

2.1.4. *Inter- and intra transcriber reliability*

The between and within transcribers reliability of the phonemic transcriptions of the children's speech samples was checked. A subset (10%) of the original data was retranscribed by a second, equally experienced transcriber, who was also involved in the present study. In addition, for intratranscriber reliability the first transcriber transcribed 5% of her original speech files again after at least two months. The two transcriptions were aligned with a dynamic alignment algorithm based on ADAPT (Elffers, Van Bael, & Strik, 2005). 2,444 words were retranscribed for the intrarater reliability check, and 2,699 words for the interrater reliability check. For the intrarater reliability an overall agreement score of 84.17% and a Kappa score of 0.83 were achieved at the level of individual segments (N=7,440). For interrater reliability 70.43% agreement and a Kappa score of 0.68 were calculated at the level of individual segments (N=8,532).

2.2. *Procedure*

In Table 1 the exact word selection and syllable selection criteria applied in the three studies are summed up. According to Procedure 1, adopted from Stoel-Gammon (1987), a speech sample of at least 10 word types and maximally 50 word tokens is collected. A word type with variable pronunciation can only appear twice in the sample. This criterion is operationalized as follows: the production of the target word /bɑl/ as /bɑ/ and /bɑw/ was included twice. Moreover, a syllable type has to occur in at least two different word types in order to be included in the inventory. Procedure 2, adopted from Thal et al. (1995), requires that a speech sample holds at least 10 word tokens and at most 105 utterances (note that 105 utterances may contain more than 105 words). No further restrictions are mentioned in Thal et al. (1995). In Procedure 3, adopted from Levelt et al. (2000), only primary stressed syllables are selected that conform to the Sonority Sequencing Principle. On top of that a syllable type has to occur at least twice in the sample to be included in the inventory.

The analysis is restricted to actual word productions, independent of the target, of the 30 children. Not only the size but also the content of the syllable inventories will be established following the guidelines of the three procedures.

[Insert Table 1 about here]

2.3. *Results*

Table 2 presents for each child the number of word tokens, word types, and the number of syllable tokens at the age of 24 months in a sample of 20 minutes. The number of *word tokens* in the children's data varies tremendously: from 63 to 590 tokens (median 278.5). The number of *word types* differs as well between the 30 subjects and ranges from 15 to 147 (median 92) types. Furthermore, the number of syllable tokens ranges from 101 tokens to 712 tokens, with a median of 409.5. Thus, Table 2 shows a lot of variation in the amount of speech data in the samples to be analyzed.

[Insert Table 2 about here]

According to the proposed selection criteria a sample was taken from the available data at age 24 months for all toddlers. First of all, the number of syllable tokens in the samples was counted for each procedure. The number of syllable tokens varies for Procedure 1 from 59 to 97 tokens (median 76), for Procedure 2 from 101 to 367 (median 208), and for Procedure 3 from 60 to 484 (median 255). Next, the number of syllable types that occurred in each selected sample was tallied. In Table 3 the syllable inventory size for each child, calculated separately for each procedure, is given. Table 3 displays for Procedure 1 a median number of syllable types of 4 (range 3-7), for Procedure 2 a median number of syllable types of 6 (range 4-9), and for Procedure 3 a median number of syllable types of 5 (range 3-8). Hence, the median number of syllable types differs between the three procedures. Moreover, the range of Procedure 1 is smaller than the range of the other two procedures. It is also striking that for each individual, except for S6 and S8, a different inventory size is calculated according to each different procedure. For example, Procedure 1 yields for S5 three different syllable types, Procedure 2 seven different syllable types, and Procedure 3 only five types. Taken together, a median difference of two types appears between Procedures 1 and 2 (range 0-5). Between Procedures 2 and 3 the median difference is one type (range 0-4). The median difference in number of types between Procedures 1 and 3 is also one (range 0-3).

[Insert Table 3 about here]

The syllable inventories in Table 3 differ significantly in size (Friedman test: X^2 = 28,896; $p < 0.01$; df = 2). The inventories measured following Procedure 1 differ significantly from Procedure 2 (Wilcoxon Signed Ranks Test, 2-tailed: Z = -4,103; $p < 0.01$) as well as from Procedure 3 (Wilcoxon Signed Ranks Test, 2-tailed: Z = -2.060; $p < 0.05$). Moreover, the inventory sizes calculated following Procedure 2 are significantly different from the ones in Procedure 3 (Wilcoxon Signed Ranks Test, 2-tailed: Z = -4.123; $p < 0.01$). In sum, the application of the three procedures results in substantially different inventory sizes.

Turning to the content of the syllable inventories, for each syllable type the number of subjects that actually produced a particular type was computed. Table 4 shows the number of children that have a particular syllable type in their inventory according to the three procedures. Syllable types V, CV and CVC are part of the syllable inventories of all the subjects according to the 3 procedures. But for all the other syllable types the three procedures yield different outcomes. Table 4 shows that Procedure 2 consistently yields a larger number of children with a particular syllable type in their inventories. In addition, Procedure 1 always leads to the smallest number of children with a particular syllable type in their inventory.

[Insert Table 4 about here]

2.4. *Discussion*

In the literature different procedures are used for compiling syllable inventories from transcribed speech. Procedural guidelines differ in several respects. A first difference relates to the word and/or syllable selection criteria, for instance, are all words or syllables selected from the transcript even when they are repeated or occur as different variants? Another difference across studies concerns the sample size: in some studies a minimum and/or maximum amount of data is specified, while in others no restriction is applied. Thirdly, studies vary as to unit of selection, that is, analyses of syllable inventories are carried out on the complete set or a selection of the syllables in a transcript, or the complete set of words or a subset thereof is selected, or the selection is restricted to a number of utterances from the transcript. In order to study the effect of different methodological guidelines on the resulting syllable inventories, three different procedures adopted from the literature were applied on the data of 30 subjects at the age of 24 months.

The main finding is that the number of syllable types in the inventories differed significantly between the three procedures. Moreover, the number of children with a particular syllable type in their inventory also differed depending on the procedure used. Thus, the findings of Study 1 indicate that the selection criteria play a decisive role in the establishment of a syllable inventory of spontaneous speech samples and eventually lead to different results. The size of the syllable inventories, as well as the particular syllable types in the inventories are influenced by the selection procedure.

From Study 1 it can also be concluded that a 20-minute sample contains a variable number of words and syllables. The data presented in Table 2 clearly show that the samples contain different amounts of words and syllables. Thus, the question remains whether the differences in inventory sizes are a direct consequence of the smaller versus larger sample sizes or from the type of words and syllables that were selected. This issue will be taken up in Study 2: if the selection criteria are held constant, and only the number of items in the sample is consistently varied, how does that procedure influence the syllable inventories?

3. Study 2 – The effect of sample size on the size of syllable inventories

Study 1 revealed that applying different procedures to one and the same data set leads to quite different syllable inventories, both in terms of the size and the content of the inventories. The question addressed in Study 2 is: What is the impact of the sample size on the size and the content of the syllable inventories?

3.1. *Method*

3.1.1.*Participants*

In this study the same data are used as in Study 1, namely the observation sessions of the 30 subjects at the age of 24 months.

3.1.2.*Bootstrapping procedure*

In this study the effect of the size of a sample on the resulting syllable inventory will be examined by means of a bootstrapping procedure. The aim of bootstrapping is to estimate the statistical distribution of a variable by means of resampling (Efron, 1979; Hesterberg, Moore, Monaghan, Clipson, & Epstein, 2005). For this purpose, samples of increasing size will be drawn from the transcriptions at age 24 months. Other selection criteria will remain constant: a syllable type has to occur minimally twice in the sample in order to be included in the inventory. This criterion is applied because transcription errors may occur since the data are taken from hand-made transcriptions.

The flowchart in Figure 1 summarizes the procedure for drawing a sample for each individual child's data from the transcript at 24 months. The procedure consists of several steps which were implemented in a Perl script. In the flowchart the following steps are taken:

1) All syllable tokens are selected from the transcript (provided that each type occurs at least twice). K indicates the number of selected syllables, the size of the complete sample.

2) From this selection a random sample (s_i) of k syllable tokens is drawn. At the start k is arbitrarily set to 25 tokens.

3) The syllable inventory size is determined, i.e. the number of different syllable types in the sample.

4) The inventory size is computed for 1,000 random samples of size k taken from the available set of syllables.

5) The average inventory size is calculated of these 1,000 samples.

[Insert Figure 1 about here]

The effect of sample size will be measured by monitoring the size of the syllable inventory with an increasing sample size. That is, starting from a small sample size (arbitrarily set at 25 syllables), the size is systematically increased with a fixed number of syllables (this increment is arbitrarily set to 25 syllables). Each time steps 2 to 5 are repeated until the selected sample size leads to less than 1,000 unique random samples (i.e. the stopping rule). The binomial coefficient (C(K, k), equation (1)) is used to compute the number of unique combinations of size k that can be drawn from a sample of size K. For instance, if a transcription contains 30 syllable tokens (K = 30) then 142,506 unique combinations of 25 syllables are possible (k = 25).

(1) $C(K,k) = K! / (k! * (K - k)!)$

3.2. *Results*

The bootstrapping procedure outlined in the previous section was applied for all subjects at the age of 24 months. Figure 2 illustrates the relationship between sample size and syllable inventory size for one subject in the study, namely S4. More specifically, each point in Figure 2 represents the mean syllable inventory size for the 1,000 sub samples and its associated 95% confidence interval given the selected sample size on the horizontal axis. The graph clearly shows that with an increase of the sample size, there is also an increase of the number of different syllable types in the inventory. When the selected sample size is small there are few syllable types in the inventory. For instance, with sample size k=25, the inventory comprises on average 4 types, and the 95% confidence is large, somewhere between 2 and 6 syllable types. When the selected sample size increases, also the number of different types in the inventory increases, and the confidence interval becomes smaller, i.e., the estimate of the syllable inventory becomes more and more precise. When the sample contains 575 syllable tokens a ceiling effect occurs: the number of types in the inventory does not show a significant increase anymore.

[Insert Figure 2 about here]

The tight relationship between sample size and the size of the syllable inventory shown in Figure 2 for participant S4, can be expressed as a Pearson correlation coefficient: 0.798, $p<0.01$. A similar high correlation was found in the data of all 30 subjects involved in this study: the Pearson correlation coefficient between the sample size - the number of syllable tokens- and the syllable inventory size ranged from 0.483 to 0.853 (median = 0.773) and turned out to be significant ($p< 0.01$) in all cases. In other words, the larger the number of syllable tokens available in the original sample of a child, the larger the number of syllable types in the inventory.

3.3. *Discussion*

Typically, spontaneous speech samples, even of equal duration – contain different amounts of speech material. The corpus analyzed in the present paper is no exception: Table 2 displays a lot of interindividual variation. The table illustrates that although a sample of 20 minutes vocal activity was transcribed for each child at the age of 24 months, quite large differences are manifest in the total number of word tokens (range = 63-590) and syllable tokens (range = 101-712). Hence the available material that can be analyzed in a syllable inventory study differs from child to child, and – in a longitudinal design – from age to age. Thus, the question becomes crucial whether the size of a sample influences the syllable inventory size. In order to investigate the effect of sample size on the inventory, the sample size was systematically increased with 25 syllable tokens for each subject while each time the syllable inventory was determined by means of a bootstrapping procedure. A positive significant correlation was established between the number of syllable tokens in a speech sample and the eventual syllable type inventories of the subjects. In other words, the probability of measuring a large syllable inventory in a speech file of a child that contains a lot of syllable tokens is higher than in a speech file of a child that includes fewer syllable tokens. This implies that in order to reliably compare syllable inventory sizes between the subjects a fixed sample size should be maintained. Comparing the inventories without a fixed sample size for all subjects, would show differences between the children that should be attributed to sample size differences instead of to divergent phonological development. For instance, in the literature speech samples are used that vary from 10 minutes (e.g. Pharr, Bernstein Ratner, & Rescorla, 2000) to 30 minutes (e.g. Keren-Portnoy et al., 2009). Obviously, not all children produced the same amount of syllables in those 10- or 30-minute-samples. Evidently, the results from these different studies cannot be compared due to their difference in sample size, and even the comparison of the children participating in the individual studies is questionable.

In addition, in the literature the amount of data to be analyzed is sometimes defined as a fixed number of utterances or words. However, a fixed number of utterances or words does not automatically guarantee that the variation in sample size is controlled. For instance Thal et al. (1995) attempted to control for sample size by including 105 fully intelligible utterances in each child's language sample. But an utterance can include more than one word. Thus, this lenient criterion for sample selection may have caused differences in sample size between the subjects. On top of that, equal numbers of words do not necessarily mean that equal numbers of syllable tokens are analyzed. For example Stoel-Gammon (1987) restricted her analysis to maximally 50 word tokens. However, the inclusion of maximally 50 words implies that also a sample with 35 words fulfills the requirement of having maximally 50 words. Thus this word inclusion criterion may not only result in different numbers of *words* in children's samples, but also, and more crucially, different numbers of *syllables.* Word tokens may contain different numbers of syllable and thus cause different sample sizes between subjects. That is, selecting 50 monosyllabic words and 50 multisyllabic words clearly leads to different sample sizes with respect to the number of syllable tokens, and since that number highly correlates with the syllable inventory size, the resulting differences in syllable inventories may simply be due to the different sample sizes.

In sum, in order to reliably compare phonological development inter-subjectively and intra-subjectively a predetermined sample size for analysis is highly recommended. This sample should be at all data points and for all children equal in size, since a significant positive correlation exists between the size of the speech sample and the measured syllable inventory. In the next paragraph a new procedure will be proposed in which the findings of the Study 1 and Study 2 will be implemented. The procedure will be applied to the data of 30 children acquiring Dutch so as to gain insight in the development of their syllable inventories.

4. Study 3: Syllable inventory size, content and order of emergence: a new procedure

Study 2 empirically showed that the size of syllable inventories depends crucially on the size of the speech sample from which they are drawn. Hence, in order to compare syllable inventory sizes between and within subjects a fixed sample size should be used. Also, normalization is recommended to prevent a sampling bias. In Study 3 a bootstrapping procedure will be defined and implemented in order to determine the development of the syllable inventories of the 30 participants in the present study, and to determine the content and the order of emergence of the syllable types.

4.1. *Method*

4.1.1. *Participants*

Data were collected from a group of 30 typically developing children living in the Dutch speaking part of Belgium. More details can be found in Section 2.1.

4.1.2. *Procedure*

An analysis with bootstrapping is carried out on all monthly observations of the 30 subjects starting at word-onset. The starting point of word onset was identified following the criteria set out by Vihman and McCune (1994). The children's ages at the word-onset range from 10 to 17 months (median=13 months). Syllable inventories are compiled cumulatively: each monthly data file holds data of the actual month and the previously recorded months starting from word onset. Drawing up an inventory in a cumulative manner entails that once a syllable type has occurred in the inventory it remains in the inventory. For this analysis the bootstrapping method that was introduced in Study 2, is applied. This time a predetermined instead of increasing sample size will be used. For the content of the inventory and the order of emergence a conservative strategy is applied: a syllable type should occur in 95% (i.e. confidence level of 95%) of the resamples in order to enter the syllable inventory. The flowchart in Figure 3 summarizes the procedure.

[Insert Figure 3 about here]

The complete data set consists of 570 monthly observations (19 observations for 30 subjects). 355 observation sessions remain after excluding the observations prior to word-onset. Figure 4 provides an overview of the number of observation sessions that are available for analysis as a function of sample size. This figure shows for example that for a sample size of 600 syllable tokens approximately 150 observation sessions are available, whereas a sample size of 1,650 tokens only allows 50 observation sessions to be included. In brief, the larger the (fixed) sample size, the fewer observation sessions are available for analysis.

[Insert Figure 4 about here]

The aim of this study is to provide a developmental view of syllable type development in a large group of toddlers starting from their word-onset to 24 months of age. However, in observation sessions at the start and one or two months after word-onset many of the subjects did not produce a lot of word tokens yet. Hence, choosing a very large sample size would lead to the exclusion of many observation sessions. In order to preserve a reasonable amount of data, the sample size was arbitrarily set to 100 tokens (k=100). This sample size takes into account developmental data from the early word stage onwards. 259 observation sessions (out of a total of 355) met this sample size criterion. A sample size of 100 tokens in this study means that a median number of 8.5 (range 5-12) observation sessions for each child could be analyzed. The syllable inventories of the 30 children are categorized relative to their chronological age. That is, all available observations of subjects with the same chronological age in months are taken together to calculate the median size of the syllable inventory of that particular age group as a whole.

In order to establish the order of emergence of syllable types a tree-structure covering all observation sessions is created. First, the types occurring in the first available observation that includes word productions and then the type(s) that emerge in the following months are set out. In addition to the tree-structure a cluster analysis is conducted. Each syllable type is entered as a variable and each age of the subject as a case in a SPSS database. Next an agglomerative hierarchical cluster analysis, using 'between-group linkage' and the 'simple matching' technique for binary variables was performed, which searches successive clusters by merging variables into previously established clusters. The process of clustering is based on the similarity or proximity of the syllable types: syllable types that usually co-occur or are often co-absent have high proximity scores.

4.2. *Results*

4.2.1. *Inventory size and content*

Table 5 shows the syllable inventories for the 30 subjects by chronological age. The median syllable inventory size increases from 4 to 6 syllable types during the time period from 13 to 24 months. Large ranges indicate that a lot of variability exists between the inventory sizes of the children at each chronological age. Moreover the distance between the child with the smallest and the largest syllable inventory increases with age. In other words, the range at 13 months of age is 3 to 6 types, whereas at age 24 months this range varies from 3 to 10 types. In Table 5 the scores for the 5^{th}, 10^{th}, 25^{th}, 75^{th}, 90^{th}, and 95^{th} percentile are given as well and show the development from the first occurring words to 24 months of age. Not until 20 months of age all 30 subjects are included in the analysis.

[Insert Table 5 about here]

In addition to the syllable inventory size, the content of the inventories was established. Table 6 displays the number of children identified with a particular type in their inventories by chronological age.

[Insert Table 6 about here]

Data are available from 13 months onwards. Starting from the age of 16 months a reasonable part of the group, at least 50% (indicated by the grey-shaded cells) used types V, CV, CVC in their word productions, closely followed by VC and CCV at respectively 17 and 19 months of age. By the age of 24 months, V, CV, and CVC have emerged in word productions of all subjects. Furthermore, syllable types VC and CCV are present in the speech data of at least half of the 30 children at the age of 24 months. Finally, CCVC, CVCC, and VCC only occur in data of 1 to 3 children by the age of 24 months.

4.2.2. *Order of emergence*

Figure 5 shows a tree structure with the emergence of syllable types. In the first observation session (indicated as “level I” in Figure 5) CV-V-CVC occur in all but one subject as indicated in the upper row of Figure 5. For 6 subjects (n=6 in Figure 5) these were the only syllable types in their inventory. This core set of syllables is completed with VC (n=7) or CCV (n=8), or both VC and CCV (n=6). The remaining types, VCC, CVCC, and CCVC emerge only sporadically in the first observation session. Syllable type CCVCC does not show up yet in any of the subjects. For some children no additional types appear later in development than the ones emerging in the first observation session. Children who do not yet produce VC or CCV, or both types in the first observation, usually start to use these type(s) in one of the following session (indicated as level II or level III). A lot of variation is apparent after the emergence of types CV, V, CVC, VC, and CCV. When children produce a syllable type with a consonant cluster, they prefer to use an onset cluster, type CCV. Twenty out of thirty children start with this type of onset cluster. Only four children show a cluster in coda position. The empirical support of these proposed orders of emergence decreases the fewer children follow the developmental pathways.

[Insert Figure 5 about here]

In addition to the order of emergence deduced from the treestructure, a hierarchical cluster analysis was conducted to identify syllable types that cluster together. Figure 6 illustrates the hierarchical cluster analysis in a dendogram and shows a coefficient to indicate the clusters' level of proximity. At the first level, types CV and V are clustered (cluster I), since these two syllable types always appear simultaneously, the coefficient is 1. At the second level a third syllable type, CVC, is added to this cluster, with a coefficient of 0.99. Turning to the next two levels, type VC and type CCV are added to cluster I with respectively coefficients of 0.74 and 0.54. In other words, five types are now clustered in cluster I: CV, V, CVC, VC, and CCV. At the same time a second cluster is created. Types VCC and CCVCC are not directly clustered to cluster

I (CV-V-CVC) but start a new cluster (II) and show a coefficient of proximity of 0.97. Type CCVC is linked to cluster II in the next level and also type CVCC is connected to this cluster with proximity coefficients of respectively 0.90 and 0.89. Hence, cluster II consists of types VCC, CCVCC, CCVC, and CVCC. Ultimately, cluster I and cluster II are combined at the final level. However, the coefficient of 0.18 indicates that the clustering of all the nine syllable types is not very strong. This implies that at this point, in developmental terms, fairly dissimilar (parts of) clusters are combined.

[Insert Figure 6 about here]

4.3. *Discussion*

Study 3 implemented a stringent procedure to chart out the expansion of the syllable inventory in early word productions of 30 toddlers acquiring Dutch. Relative to chronological age, the median syllable inventory increased with 2 syllable types; starting from 4 types at 13 months to 6 types at 24 months of age. At the age of 24 months the number of syllable types ranged from 3 to 10 different types. Thus, children with similar ages differed considerably as to their inventory size.

As to the order of emergence of syllable types in children's word productions, often almost all types used in the investigated time span already appeared during the first observation session. But, for two thirds of the children an additional type occurred in a successive observation. One strong observation was that all children (with the exception of one) started with at least the syllable types CV, V, and CVC. Usually, the syllable types VC, CCV, or both emerged simultaneously or after the emergence of CV, V, and CVC. When children produce a syllable type with a consonant cluster, they prefer to use an onset cluster, type CCV. Nonetheless sometimes also other types with a consonant cluster in either onset or coda position emerged. However, no clear order of emergence could be determined for these remaining types.

Similarly, no order of occurrence could be defined for the types that emerged simultaneously in the first observation. For instance, S18 used CCV already in the first observation session and prior to VC, while S19 did not produce VC or CCV in the first observation, but in the following observation sessions VC occurred prior to CCV.

Overall, the hierarchical cluster analysis corroborates the findings shown in Figure 5. Particularly syllable types CV, V, and CVC cluster together very strongly and this cluster is very often linked to syllable type VC, and together with CCV these four types constitute the *first type* cluster. Hence, this cluster contains all syllable types that emerge in the first observation session of the majority of children. The remaining syllable types with onset, coda, or both consonant clusters are connected in a second cluster as well. This cluster comprises syllable types that typically do not co-occur with types in the first type cluster or do not even mutually co-occur.

5. General discussion and conclusion

The principal aim of this paper was to investigate syllable inventories on the basis of transcriptions of spontaneous speech of thirty toddlers acquiring Dutch. In order to arrive at a methodologically sound description of the linguistic production of young children, differences between children's speech volubility were taken into account resulting in the articulation of an explicit and formally defined procedure for compiling syllable inventories.

5.1. *Methodological issues in syllable inventory studies*

How to chart syllable inventories in spontaneous speech corpora? Inspection of the literature shows that often various selection criteria were applied to compile a speech sample. Strikingly, there is no consensus about the procedure. Studies varied in their word- and syllable selection criteria, sample size selection, and unit of selection.

A first question was whether differences in selection criteria lead to differences in the syllable inventories. Therefore, the first experiment compared three procedures, viz. the ones adopted from Stoel-Gammon (1987), Thal et al. (1995), and Levelt et al. (2000). The comparison between the three procedures, which differed in their selection criteria, resulted in substantial differences in the syllable inventories. Thus, ideally one identical procedure to chart out syllable inventories should be used in the literature in order for results to be comparable.

5.2. *The relationship between amount of speech data and syllable inventory size*

In the second study one critical, though often neglected factor, i.e. sample size and its effect on the syllable inventory was tested (Hutchins et al., 2005; Rowland et al., 2008; Taelman et al., 2005; Tomasello & Stahl, 2004). Indeed, a lot of variation in children's volubility was shown resulting in considerable differences in the number of word and syllable tokens (see also Molemans, Van Severen, van den Berg, Govaerts, & Gillis, 2010). The current study yielded for thirty children a positive correlation between the selected sample size and the syllable inventory size. Thus, the larger the number of syllable tokens in an observation session, the larger the inventory size. Notwithstanding this obvious link between sample size and syllable inventory size, prior studies did not, or inappropriately, control for sample size.

It is remarkable that the majority of syllable inventory studies did not address the issue of sample size explicitly or did so in an imprecise way. The present paper shows that disregarding a controlled sample size has fundamental consequences for the outcomes of inventory studies. This finding has serious consequences. For instance, syllable type development has been studied in typically developing children in comparison with late-talking children or children with Specific Language Impairment (e.g. Carson, Klee, Carson, & Hime, 2003; Paul & Jennings, 1992; Pharr et al., 2000; Rescorla & Bernstein Ratner, 1996; Thal et al., 1995). An important observation is that the SLI and late-talking children have smaller syllable type inventories and delayed development of complex syllable types as compared to typically developing age-matched peers (Carson et al., 2003; Thal et al., 1995). However, late-talkers and SLI children are typically less voluble than typically developing children, and hence their speech samples differ in size as compared to typically developing children. The significant positive correlation between sample size and inventory size revealed in the second study of this paper implies that sample size should be controlled in order to validly compare results. Thus, when researchers neglect the selection of a balanced sample size, differences between language-delayed and typically developing children may well be the result of the method applied in the study and not necessarily characteristic of the children’s impaired speech.

5.3. *Syllable inventory size, content, and order of emergence: a new procedure.*

In the final study a new procedure was introduced to address syllable inventory development. An empirically underpinned methodology with a fixed sample size to determine syllable inventories was proposed. To control for sampling bias, a normalization procedure was implemented (Efron, 1979; Hesterberg et al., 2005).

The inventories of 30 toddlers acquiring Dutch were established relative to children's chronological age. Median inventory sizes increased from 4 to 6 syllable types from age 13 to 24 months. However, a lot of variation was noticed in the size of the inventories of children of the same age. Analyzing the same dataset, van den Berg (2012) found that, contrary to the comparison by chronological age, the comparison by lexicon size, i.e. the cumulative number of word types, did not show as much variation as indicated by the smaller ranges of usually 2 to 3 types. Hence, children that have a more or less similar linguistic level, i.c. lexicon size, also have similar syllable inventory sizes. Van den Berg (2012) compared the correlation coefficients of lexicon size and inventory size on the one hand and chronological age and inventory size on the other hand. The larger correlation coefficient between lexicon size and inventory size indicated that lexicon size is a slightly better predictor of (syllable) inventory size than chronological age. This corroborates the findings of Stoel-Gammon (2011) who concludes that phonological skills are more tightly related to the lexicon (or "lexical age") of children than to their chronological age. Therefore, it is recommended to investigate children's phonological abilities, such as drawing syllable inventories, also in relation to their lexicon size.

As to the content of the syllable inventories, children's early words show a limited number of syllable types and they continue to make use of only these types long after word-onset. The syllable types available in the early lexical stage were V, CV, VC, CVC and CCV. Only few children acquired additional types (CCVC, CVCC and VCC) during this time period. In sum, children did not rapidly increase their syllable inventory within the early lexical stage.

Besides inventory size and content, the order of syllable type emergence in toddlers' word productions was investigated. A core set of syllable types, i.e. CV, V, and CVC, were already used during the first observation of all (but one) of the children. Most children acquired type VC, type CCV, or both types together with or soon after this initial set of syllable types had emerged. In sum, in early lexical productions a relatively invariant pattern of syllable type emergence, but over time this pattern becomes more and more variable. Later in development several paths of development were differentiated without any apparent consistent line.

5.4. *Theoretical implications*

When establishing the order of emergence of syllable types in children, researchers tend to search for invariant patterns exhibited by all children. Cases in point for Dutch are Fikkert (1994) and Levelt et al. (2000). A typical outcome of these studies is that particular syllable types emerge prior to others, yielding distinct developmental stages. For instance, Levelt et al. (2000) indicated a straightforward developmental path at the start of development followed by two additional pathways later in development with regard to consonant cluster development. However, no such strictly differentiated developmental stages account for the entire developmental trajectory of syllable types of any of the 30 subjects in the present study. Only one invariant pattern was found: a fixed set of syllable types emerges at the very start of the lexical stage, consisting of CV, V and CVC syllables. But the pattern of development became far less general over time indicating substantial variation in the emergence of syllable types between the subjects.

Invariant patterns of development imply that children go through particular developmental stages. For instance, Fikkert (1994) reported that during the first lexical stage the coda position remains empty. However, our results show that almost all children produce coda elements in their early word productions. The data reported in the present paper did not reveal one developmental path along which children expand their syllable inventory. The analysis yielded some general lines of development but at the same time also considerable variation between the 30 toddlers. This finding corroborates previous studies that demonstrated variation between children in their phonological development (a.o. Demuth, 1997; Grijzenhout & Joppen-Hellwig, 2002; Stoel-Gammon & Cooper, 1984; Vihman, Ferguson, & Elbert, 1986; Vihman, DePaolis, & Keren-Portnoy, 2009; Vogel Sosa & Stoel-Gammon, 2006).

Taken together, in keeping with previous studies, simple syllable types emerged prior to complex types in the spontaneous speech samples of 30 typically developing toddlers. Nevertheless, syllable types CV, V, and CVC emerge *simultaneously* and are the first types to occur in the lexical period of children.

5.5. *Conclusion*

The present study investigated methodological issues that play an important role in measuring children's spontaneous speech, such as charting a syllable type inventory. It was shown that different selection criteria substantially influence the syllable inventory in terms of size and content. Since the replicated procedures did not implement a restriction on the amount of data it was plausible that the size of the speech samples affected the outcomes. Indeed, the influence of the sample size on the syllable inventory size was significant: sample size is positively correlated to the amount of syllable types. A new, empirically underpinned procedure to reliably compare phonological development, in which a fixed sample size equal for all data points and for all children is recommended, was proposed. The implementation of a bootstrapping procedure showed that very young children acquiring Dutch start consistently with syllable types CV, V, and CVC to produce their first words. The next types to occur were VC and CCV, though this pattern was less consistent. The order of emergence of the remaining syllable types was characterized by a lot of inter-individual variation, though onset clusters were the first clusters to appear in the majority of children.

Although this paper covered several important issues which are relevant for the methodology of drawing syllable inventories, some issues were left aside in the analyses, e.g. variables such as word length, stress pattern, position of the syllable within a word. It goes without saying that all of the above variables play important roles for syllables and influence the syllable type inventory. However, it was out of the scope of this paper to consider the syllable type in all these different linguistic situations.

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FIGURE CAPTIONS

Figure 1: Flowchart of the procedure for drawing a syllable inventory from a sample by means of the technique of bootstrapping

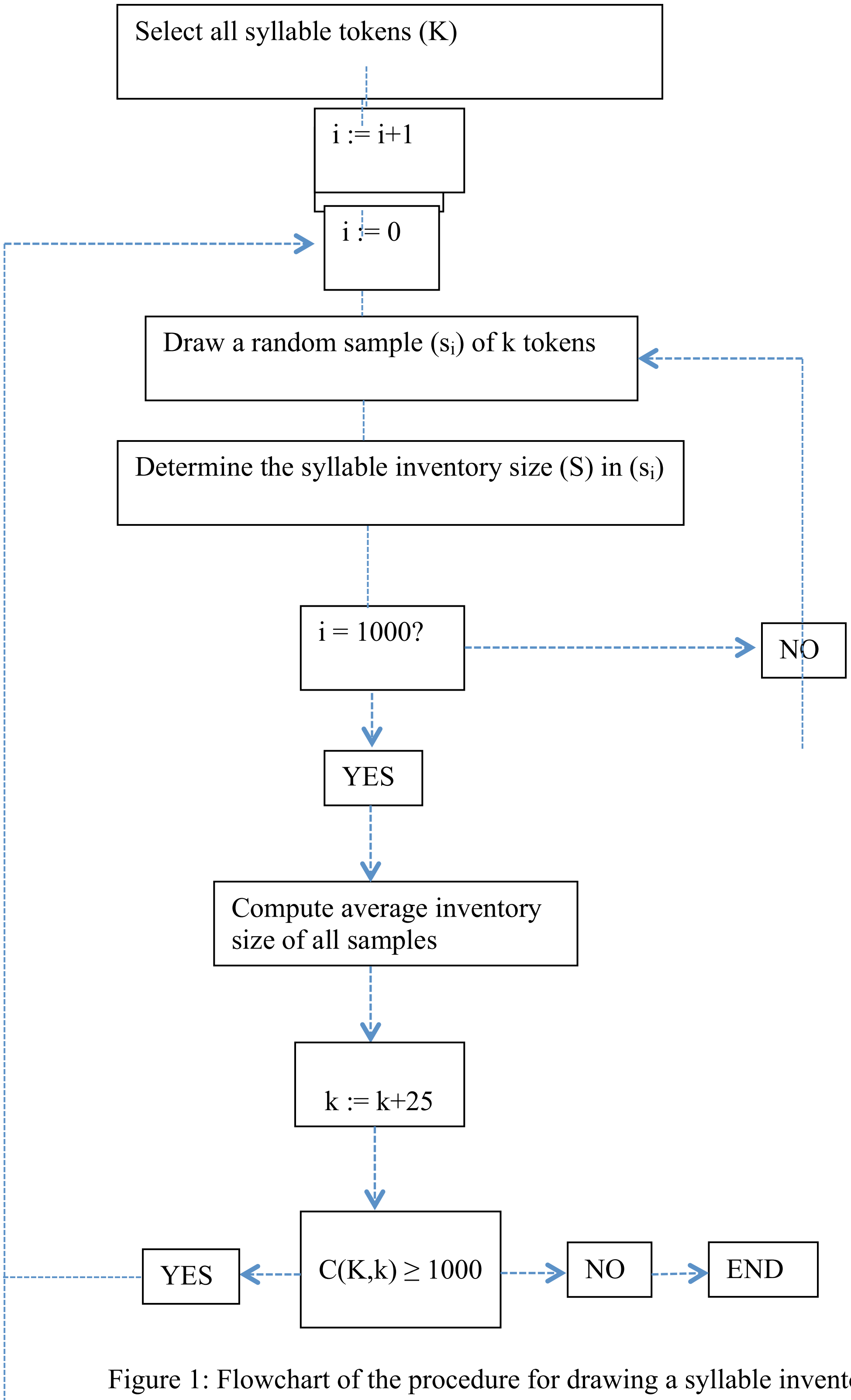
Figure 2: Mean number (and 95% confidence interval) of syllable types as a function of sample size

Figure 3: Flowchart of the procedure proposed for drawing syllable inventories from speech samples by means of the technique of bootstrapping

Figure 4: Number of recording sessions as a function of sample size

Figure 5: Order of emergence of syllable types

Figure 6: Dendogram representing clusters of syllable types



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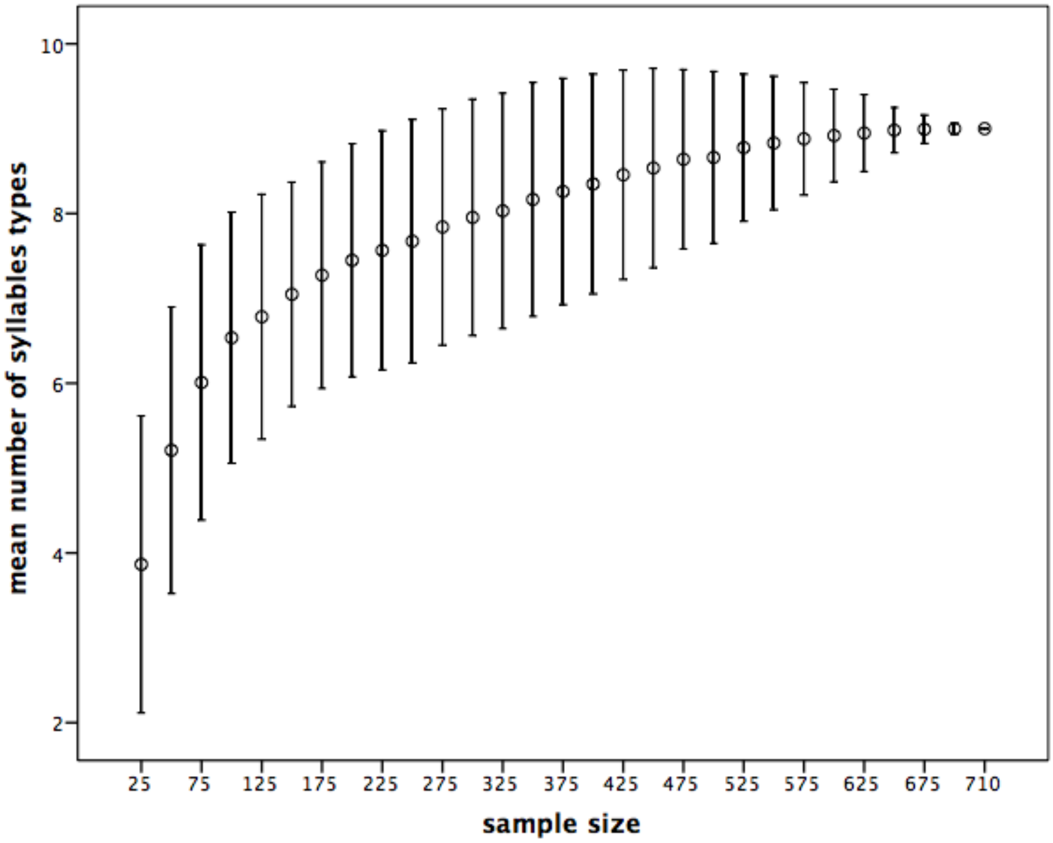

Figure 2: Mean number (and 95% confidence interval) of syllable types as a function of sample size

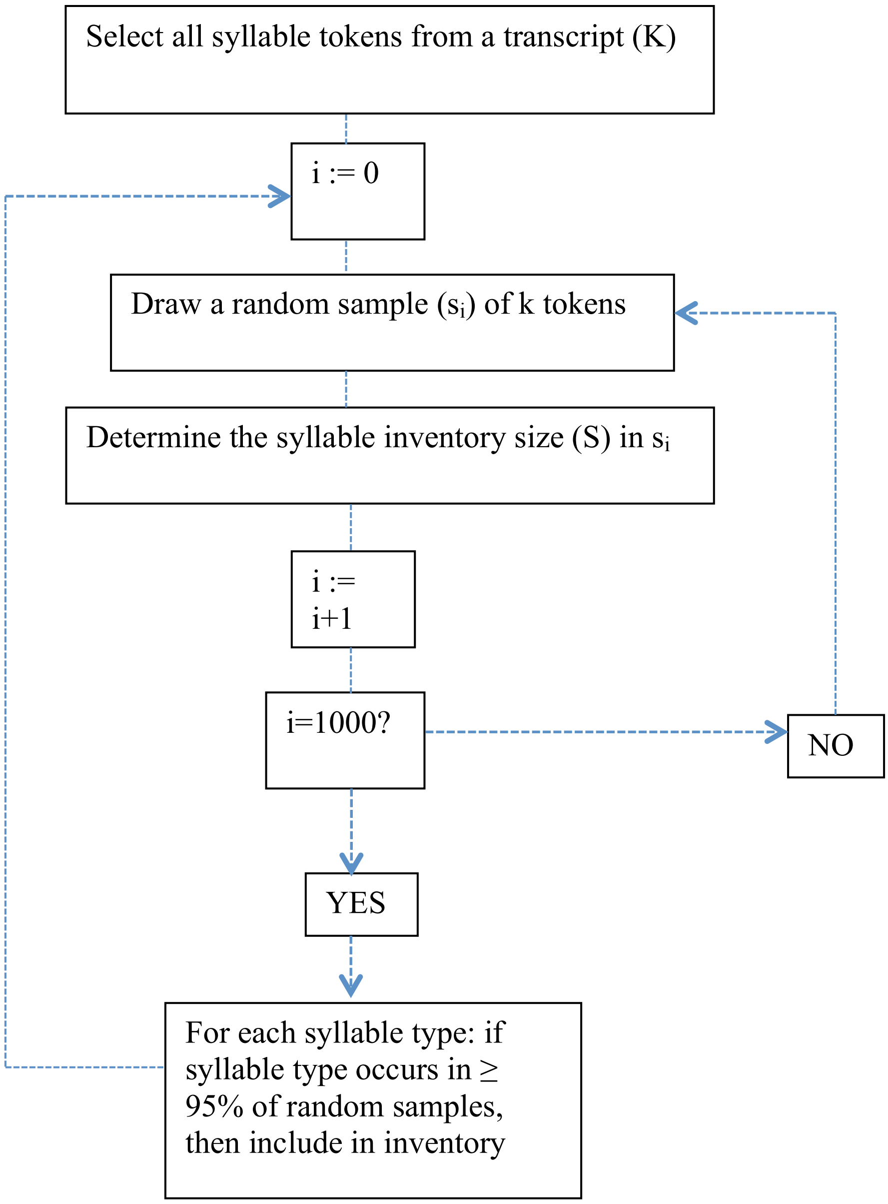

Figure 3: Flowchart of the procedure proposed for drawing syllable inventories from speech samples by means of the technique of bootstrapping

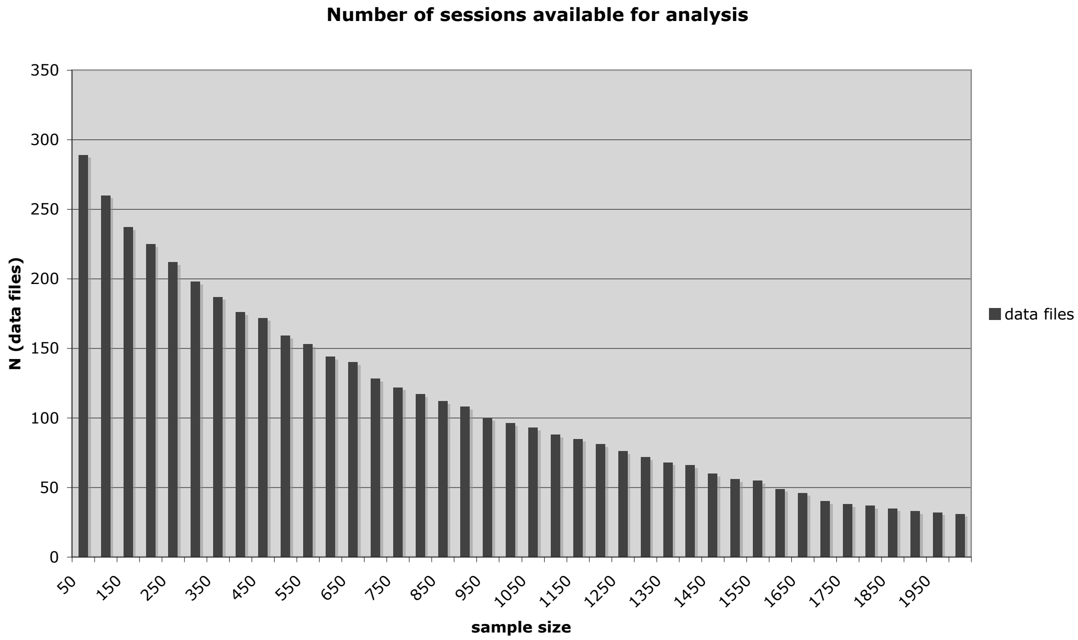

Figure 4: Number of recording sessions as a function of sample size

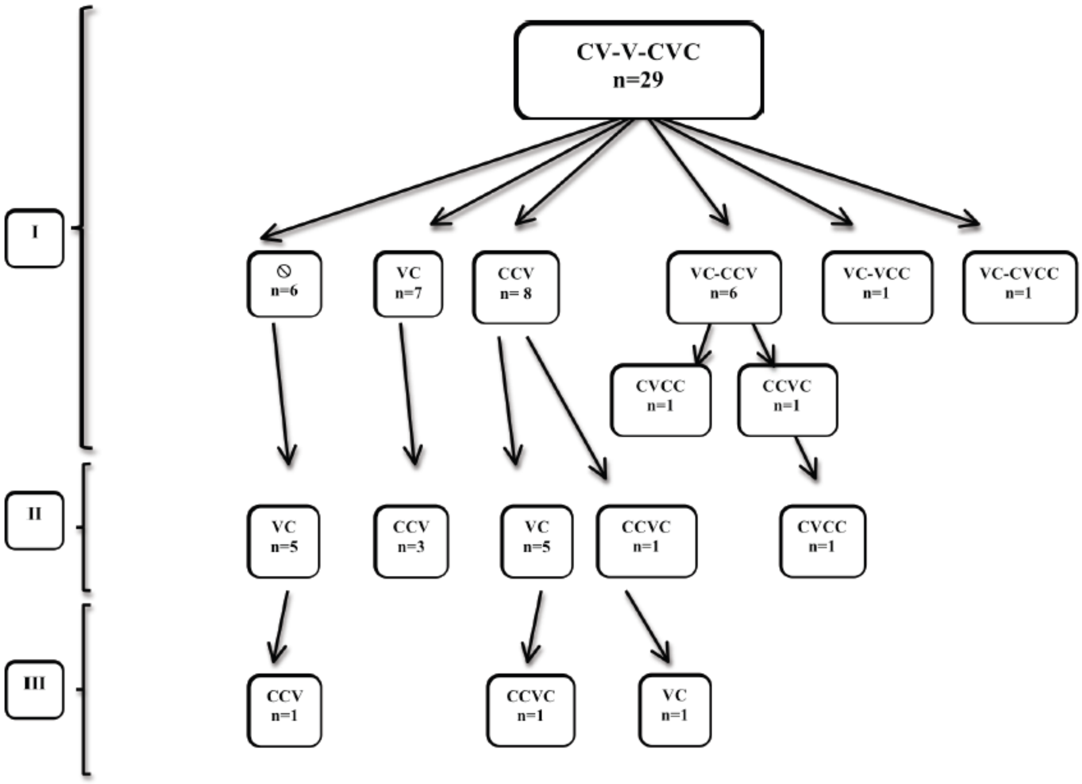

Figure 5: Order of emergence of syllable types

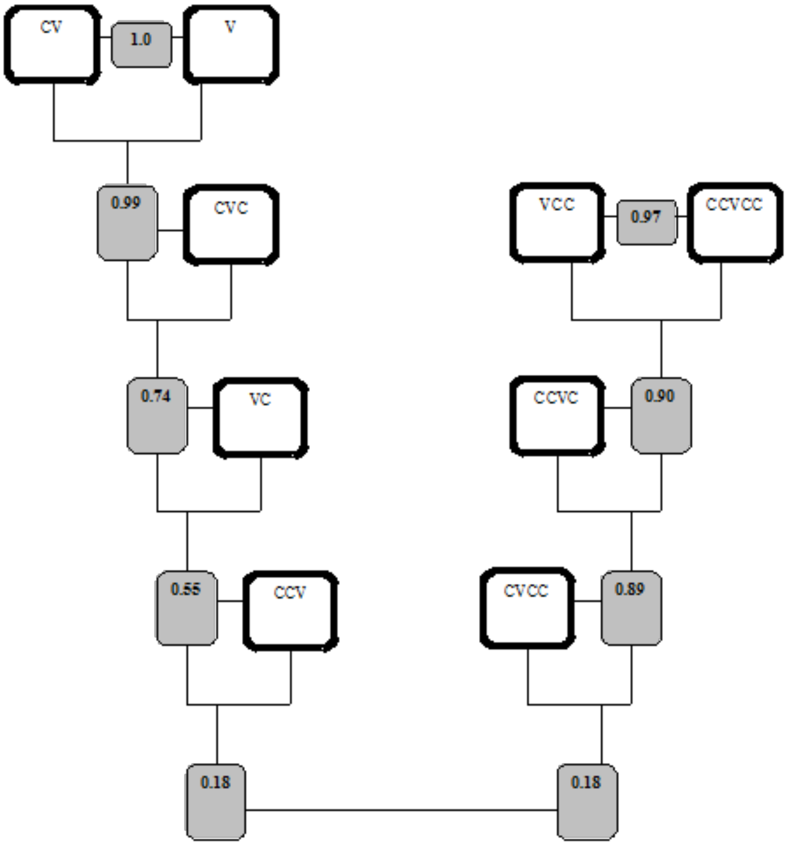

Figure 6: Dendogram representing clusters of syllable types

TABLE CAPTIONS

Table 1: An overview of the selection criteria applied in the replicated studies

Table 2: Number of word tokens, word types, and syllable tokens in 30 participants at 24 months of age

Table 3: Syllable inventory size measured following guidelines of three procedures (1, 2 and 3)

Table 4: Number of participants that have a particular syllable type in their inventory at the age of 24 months according to the three procedures (1, 2 and 3)

Table 5: Median size (ranges), and percentiles of syllable inventory size as measured for 30 typically developing toddlers

Table 6: Syllable types in 30 typically developing toddlers relative to chronological age

Table 1: An overview of the selection criteria applied in the replicated studies

Procedure 1 ~ Stoel-Gammon (1987)	Procedure 2 ~ Thal et al. (1995)	Procedure 3 ~ Levelt et al. (2000)
• min 10 word types • max 50 word tokens • max 2 two variants of a particular word type • syllable shape has to occur in at least two different word types	• min 10 word tokens • max 105 utterances	• all available words included • min two tokens of a particular type • only primary stressed syllables • only syllables conform the Sonority Sequence Principle

Table 2: Number of word tokens, word types, and syllable tokens in 30 participants at 24 months of age

Child	# word tokens	# word types	# syllable tokens
S1	377	117	597
S2	317	112	413
S3	427	97	656
S4	590	137	712
S5	324	83	444
S6	99	15	132
S7	225	90	352
S8	276	80	390
S9	240	108	367
S10	227	117	384
S11	245	63	410
S12	129	43	173
S13	251	105	350
S14	309	147	484
S15	192	63	347
S16	319	58	535
S17	233	84	345
S18	471	134	707
S19	214	73	307
S20	366	94	461
S21	281	120	379

S22	354	97	475
S23	286	107	426
S24	291	102	426
S25	63	37	101
S26	155	34	242
S27	325	89	499
S28	320	96	422
S29	228	72	409
S30	152	60	228
Median	278.5	92	409.5
Range	63-590	15-147	101-712

Table 3: Syllable inventory size measured following guidelines of three procedures (1, 2 and 3)

Child	Procedure 1	Procedure 2	Procedure 3
S1	4	5	4
S2	4	7	5
S3	4	7	6
S4	6	8	8
S5	3	7	5
S6	4	4	4
S7	5	8	4
S8	5	5	5
S9	4	9	5
S10	6	6	4
S11	5	5	4
S12	5	6	5
S13	6	7	7
S14	5	7	8
S15	4	6	4
S16	3	7	5
S17	4	6	4
S18	7	9	7
S19	5	8	6
S20	3	6	5
S21	4	8	7

S22	7	6	6
S23	4	7	5
S24	3	8	6
S25	6	6	4
S26	4	4	3
S27	6	6	5
S28	5	6	6
S29	4	5	4
S30	4	5	5
Median	4	6	5
Range	3-7	4-9	3-8

Table 4: Number of participants that have a particular syllable type in their inventory at the age of 24 months according to the three procedures (1, 2 and 3)

Syllable type	Procedure 1	Procedure 2	Procedure 3
V	30	30	30
CV	30	30	30
VC	22	29	28
CVC	30	30	30
CCV	15	27	17
CVCC	5	16	6
CCVC	7	17	12
VCC	0	9	3
CCVCC	0	3	0
CCCV	0	3	0
VCCC	0	1	0
CVCCC	0	1	0

Table 5: Median size (ranges), and percentiles of syllable inventory size as measured for 30 typically developing toddlers

Chronological age (months)	13	14	15	16	17	18	19	20	21	22	23	24
# subjects	*3*	*4*	*11*	*15*	*22*	*26*	*28*	*30*	*30*	*30*	*30*	*30*
median (range)	4(3-6)	4(2-6)	4(2-7)	5(2-7)	5(2-8)	5(2-8)	5(2-8)	5(2-8)	5(2-8)	5(2-8)	6(3-10)	6(3-10)
pc 95	6	6	6	6	7	7	7	7	7	7	7	7
pc 90	6	6	6	6	6	7	7	7	7	7	7	7
pc 75	6	4	4	5	6	6	6	6	6	6	6	6
pc 25	3	3	4	4	4	4	4	5	5	5	5	5
pc 10	3	3	3	3	4	4	4	4	4	4	4	4
pc 5	3	3	3	3	3	3	4	4	4	4	4	4

Table 6: Syllable types in 30 typically developing toddlers relative to chronological age

	Syllable types							
Age (months)	CV	V	CVC	VC	CCV	CCVC	CVCC	VCC
13	3	3	1	1	2			
14	4	4	4	1	3			
15	11	11	11	4	5			
16	15	15	15	9	7			1
17	22	22	21	15	11	2	2	1
18	26	26	25	18	14	2	3	1
19	28	28	27	20	16	3	3	1
20	30	30	29	23	17	3	3	1
21	30	30	30	24	18	3	3	1
22	30	30	30	24	18	3	3	1
23	30	30	30	25	18	3	3	1
24	30	30	30	25	19	3	3	1