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The acquisition of initial consonant clusters in German-speaking 2-year olds

Abstract

Purpose: The aim was to explore cluster acquisition in typically developing German-speaking 2-year olds.

Method: Data from four cross-sectional studies (n=145, aged 2;00-2;11) and one eight-month longitudinal study were analysed (n=6, aged 2;01-2;04). Two different percentages of consonant clusters correct were calculated to allow a more detailed analysis.

Results: Findings showed that the majority of children produced clusters although they could not be considered to be fully acquired. Correct production significantly correlated with age. Only /gl/ and /kl/ were shown to be phonetically and phonemically acquired (75% criterion) in the older age-group. 3-element clusters were acquired at the same time as 2-element clusters and /ʃ/-clusters were acquired to the same or larger extent as non-/ʃ/ clusters when fronting/backing of /ʃ/ was accepted. Younger children produced more reductions than simplifications but this effect was less strong for the /ʃ/-clusters. Developmental realisation patterns varied depending on cluster type. Inter- and intra-individual developmental patterns could be observed which changed depending on the time of testing.

Conclusion: Findings on cluster acquisition in 2-year old German-speaking children revealed language specific differences but also similarities in comparison to results from other languages. All but two children produced clusters. However, individual variation between children was high.

Introduction

During the first years of life children acquire the sound system of their native language(s). For the majority of languages, one key element in speech development is the acquisition of consonant clusters which has been described as a more difficult and thus later developmental step than the acquisition of singletons (MacLeod, Sutton, Trudeau, & Thordardottir, 2011). For a number of languages, studies (single to larger group studies) on the age and order of cluster acquisition have been conducted and cross-linguistic differences and similarities were described (for an overview see e.g. McLeod, 2007). For some languages such as English, detailed knowledge about realisation patterns during the developmental process is available and shows that these patterns are strongly connected to the cluster constituents (e.g. Smit, 1993). Across languages, cluster reduction (the deletion of one of the cluster elements, e.g. /sneɪk/ to /neɪk/) and cluster substitution (the replacement of one cluster element for another, e.g. /krɒs/ to /trɒs/ also described as cluster simplification) are common and typical realisation patterns before the mastery of clusters (Gerrits, 2010; McIntosh & Dodd, 2008; Preisser, Hodson, & Paden, 1988; Yavaş, 2013). However, it has been demonstrated that children speaking different languages do not necessarily show identical realisation patterns for specific consonant clusters (e.g. Chin & Dinnsen, 1992; MacLeod et al., 2011; Yavaş, 2013). These findings may challenge theoretical approaches aiming to explain these patterns. One theoretical concept which is commonly referred to when explaining cluster acquisition is the sonority principle. It is assumed that clusters which have smaller sonority differences are more complex and hence are acquired later or produced more inaccurately. The principle is also applied when explaining cluster reductions, as it is assumed that the most sonorous cluster element is deleted (e.g. Ohala, 1999). Therefore, theories based on sonority predict that in clusters such as /sn/ the /n/ should be deleted. However, for clusters with smaller sonority differences, the selection of the most sonorous element is more difficult (e.g. Yavaş, Ben-David, Gerrits, Kristoffersen, & Simonsen, 2008). Those clusters (such as /sn/ in /snəʊ/) tend to be reduced to either the first or second consonant (i.e. /səʊ/ or /nəʊ/). Hence, theoretical accounts sometimes have difficulty accounting for some error patterns.

Cross-linguistic data further indicate that it might not be possible to transfer findings from one language to another. This is of importance specifically for the interpretation of cluster realisations in children with speech sound disorders. Misinterpretations can lead to an incorrect choice of therapy approach and restricted generalisation during treatment. Thus, language specific knowledge about when and how children acquire clusters is pivotal for the diagnosis and intervention of speech delays or impairments. To date there is limited knowledge about cluster acquisition in children acquiring German as their first language even though German is spoken by a large number of people across the world (Crystal, 2010). Since there is some empirical evidence that children can produce consonant clusters in words before the age of two (e.g. Krüger, 1998; Lleó & Prinz, 1996; Robb & Bleile, 1994), and reliably from 24 month onwards (McLeod et al., 2001a), the current study aimed to explore the age and order of cluster acquisition and the developmental realisation patterns in German-speaking two year olds using a large dataset and analysing a large number of German clusters.

Consonant cluster acquisition in toddlers

Previous studies have described that already 2-year olds produce consonant clusters (e.g. McIntosh & Dodd, 2008, McLeod et al., 2001a). One key aspect which needs to be considered when observing cluster acquisition is the qualitative change from non-adult to adult productions (McLeod, Van Doorn, & Reed, 2001a). Many studies have compared children’s speech against adult productions but this data do not allow for a fine-grained observation of change in cluster realisation. Different steps towards adult-like productions need to be defined (Chin & Dinnsen, 1992). Moreover, since earlier studies underline the variability in developmental patterns (Watson & Scukanec, 1997), speech development needs to be observed over time to explore different developmental trajectories.

Although there is a sound evidence base for the acquisition of clusters in English-speaking children (for a review see McLeod, 2013), data from large samples or detailed longitudinal data on cluster development in 2-year olds are still sparse. This is particularly the case for languages other than English. A range of studies focus on single case studies or address specific theoretical aspects, but do not assess the full range of cluster productions and acquisition patterns (e.g. Barlow, 2003 for an overview of Spanish-speaking children; Demuth & McCullough, 2009 reporting longitudinal data on 2 French-speaking children or Yavaş, 2013 comparing data from six different languages; for a comprehensive overview of normative data across languages see McLeod, 2007). Therefore, the study by McLeod, Van Doorn, and Reed (2001a) provided key research in applying a mixed-method approach, i.e. including a longitudinal and cross-sectional design, to explore cluster acquisition in sixteen 2-year old English-speaking children. Their data were discussed in the context of previous research and theoretical assumptions, addressing a wide range of aspects and summarising essential trends in cluster acquisition. In the following, five of the trends which are relevant for the current study are described and discussed in the context of current research.

Firstly, English-speaking 2-year olds are able to produce consonant clusters and their correctness in production increases over time (see also Dodd, 1995; Dyson, 1988; Ota & Green, 2013; Stoel-Gammon, 1987). This finding is suported by McLeod, van Doorn and Reed (2001a). However, they found that some cluster realisations were not adult-like productions and sometimes even violated the language's phonotactic rules (for English e.g. [bwɛd] instead of /brɛd/ or [fwɒg] instead of /frɒg/). They further observed adult-like realisations of clusters but also cluster reductions and substitutions in all their participants. This highlights the need to differentiate between different quantitative and qualitative measures to describe cluster acquisition, and to look at adult- and non-adult-like productions alike.

Concerning the age of acquisition (i.e. 75% of the children of one age group produced clusters correctly) McLeod (2013) reports in her literature summary that in English cluster acquisition only starts at the age around 3;06. In contrast, findings for Canadian French (MacLeod et al., 2011) show that customary cluster production (customary defined as at least 50% of children produce clusters correctly) begins between the age of 2;00 and 2;05 with the production of /bl/ /fl/ and /bw/. The cluster /bl/ was found to be acquired between the age of 2;06-2;11. Customary cluster production continues to increase during the age of 2;06-2;11 with the realisation of /fʁ/, /kʁ/, /pw/, /tr/ and /vj/.

Secondly, cluster composition impacts on when clusters are acquired: a) consonant clusters including stops are mastered before consonant clusters including fricatives (e.g. Templin, 1957). This assumption was not confirmed by McLeod et al. (2001a). Children in their cohort did not produce stop-clusters more correctly. b) two-element clusters are acquired before three-element clusters (e.g. Smit, 1993). McLeod et al. (2001a) found supporting evidence for this assumption although the overall number of elicited three-element clusters was small. In contrast, MacLeod et al. (2011) showed that French-speaking children acquired the only 3-element cluster they assessed (i.e. /skɥ/) at the same time as 2-element clusters.

Thirdly, different types of non-adult like realisation patterns can be found in children's developing phonology. Chin & Dinnsen (1992) described a large range of cluster realisation patterns for English-speaking children: a) cluster reduction, b) cluster substitutions, c) cluster deletion, d) coalescence (i.e. a single phoneme is produced which includes phonetic features from the adult cluster, e.g. /swɪm/ realised as [fɪm]), or e) production of schwa-epenthesis (i.e. /ə/ is added to a cluster, e.g. /flaɪ/ is realised as [fəlaɪ]. Findings by Smit (1993) indicated that the majority of their American English-speaking children showed cluster reductions and cluster substitutions. Cluster deletion was described as very rare and epenthesis was only mentioned for word final clusters. Coalescence was not explicitly described. The findings by McLeod et al. (2001a) on Australian children are in agreement with Smit (1993). In addition to the general realisation types Smit (1993) analysed patterns per cluster. Her findings showed that clusters containing an obstruent and either /l/ or /r/ tended to be reduced to the obstruent. Only young 2-year olds occasionally retained the /r/. For substitutions frequent gliding of /l/ and /r/ to [w] was observed. For /s/-clusters, the /s/ tended to be deleted and reduction of /s/-clusters was observed longer than for other clusters. Demuth & McCullough (2009) analysed data from two French-speaking children. For clusters consisting of an obstruent + /ʁ/ there was a dominance for retaining the obstruent. This is in agreement with findings from MacLeod & Findlay (in preparation).

Fourthly, there is a relationship between cluster reductions, substitutions and correct productions. For example, Dyson and Paden (1983) suggested three potential production patterns: either a) cluster reductions are followed by correct productions, b) cluster reductions are followed by substitutions and lastly by correct productions, or c) cluster deletions are followed by cluster reductions, substitutions and correct production. In addition, younger children produce more cluster reductions than older children. When reductions decrease, an increase of substitutions can be observed. McLeod et al.'s (2001a) cross-sectional data confirmed this trend. However, their longitudinal data showed a less clear pattern and only partly underpinned developmental sequences suggested by Dyson & Paden (1983).

Finally, cluster development over time shows variability: distinct acquisition patterns can be found for children. Not all children exhibit a linear increase of correct cluster productions; developmental patterns are often characterised by reversals and revisions. This aspect was strongly supported by McLeod and colleagues (2001a).

Consonant clusters in German

Comparable to English and French, German onsets can comprise a single consonant or a cluster with up to three consonants. A comparison between German and French cluster production is of interest, since French is one of the few languages with the same <r> realisation as German (i.e. /ʁ/). In addition, it is the only language with published data on clusters containing /ʁ/. The High German cluster system includes 23 2-element clusters in word initial position and two 3-element clusters, which can be found in childhood vocabulary (Wiese, 1996, for an overview see Table 1). Additionally, clusters such as /tsv, ps, gn, vʁ, pfʁ/ exist only in adult words which children do not recognise lexically at this age (Wiese, 1996) and were therefore excluded in the presented study design. Generally, as highlighted by Ota and Green (2013) those lexical constraints might impact on cluster acquisition.

Table I about here

The three systems show a high degree of similarity but a key difference is the occurrence of /s/-clusters in English and French, which violate German phonotactic constraints, and /ʃ/-clusters in German, with only two /ʃ/-clusters in either English or French. /s/-clusters have been proposed to exhibit a special status, with /s/ syllabified outside the onset of the syllable to form an adjunct cluster (Barlow, 2001; Yavaş, 2013). This assumption is also discussed for German /ʃ/-clusters (Bartels, 2012; Ott, Van De Vijver, & Höhle, 2006; Wiese, 1996). However, it is debated whether all /ʃ/- and /s/-clusters need to be considered adjunct clusters or only those which are in conflict with sonority principles (see e.g. Fikkert, 1994; Goad & Rose, 2009; Hall, 2000). For a more in-depth theoretical discussion on /ʃ/- cluster acquisition in German see Yavaş, Fox-Boyer, and Schaefer (in preparation).

Consonant cluster acquisition in German-speaking 2-year olds

The first researchers to document cluster acquisition in German-speaking typically developing toddlers (2 girls, 3 boys) were Lleó and Prinz (1996), focussing on the clusters /fl/ and /fʁ/ or stop + /ʁ/. Results showed that up to the age of 2;01 years the children were not able to produce the two clusters correctly but reduced these to the first element stop or /f/, thus following the sonority principle, i.e. deleting the more sonorous element of the cluster. Fox and Dodd (1999) assessed cluster acquisition in 180 children aged 1;06 – 5;11 within a cross-sectional study. Children were divided into 6-months age bands. Even though the children of the youngest age group already produced some clusters, only at the age of 3;05 some clusters were acquired (75% criterion, see Dodd, 1995) and at 4;00 years mastered (90% criterion). The analysis of reduction patterns indicated that clusters containing stops or /f/ followed by /ʁ/ were reduced mostly to their first element, which is in line with the sonority principle. In contrast, clusters containing stops or /f/ followed by /l/ were reduced either to their first or second element. Clusters containing /ʃ/ + a second consonant (C_2) were reduced to C_2, not following the sonority principle. Clusters containing /ʃ/ + /p/ or /t/ + /ʁ/ were reduced to either their third consonant (C_3) or to C_2C_3. Piske (2001) observed speech production in very early utterances of two children aged 0;11 and 2;03 years. Child 1 did not produce any clusters correctly but reduced them all. Child 2 started realising clusters, but produced mainly phonotactically inadmissible clusters such as /çl/ and /kç/. Bartels (2012) assessed cluster acquisition in six children aged 2;02-2;04 over 4 months. She found that all children but one produced a high number of non-/ʃ/-clusters already correctly at baseline (T1). At the end of the study (T5) four children produced all non-/ʃ/-clusters correctly and two children produced 65% of clusters correctly. The majority of /ʃ/-clusters were simplified by all but one child at T1. At T5 five children produced all /ʃ/-clusters correctly, when fronting or backing of /ʃ/ was accepted as correct.

In sum, the empirical evidence base for word-initial cluster acquisition in German-speaking children is still incomplete, based on small sets of data or datasets spread across a wide age range, and not unanimous in supporting theoretical assumptions such as the sonority principle. Therefore, the aim was to use large datasets from different cross-sectional studies and one short-term longitudinal study, to explore acquisition patterns in German and compare them with English (Chin & Dinnsen, 1992; McLeod et al., 2001a; Smit, 1993) and French (Demuth & McCullough, 2009; MacLeod et al., 2011). The following research questions were addressed:

1. How do clusters develop in German-speaking children between the age of 2;00-2;11 when compared to adult-like productions but also when reduction and substitution patterns are considered (trend 1)?
2. What is the order of acquisition (measured by PCCC scores) for different clusters in German (trend 2)?
    a. Are /ʃ/-clusters acquired later in comparison to other German consonant clusters?
    b. Are 2-element consonant clusters acquired before 3-element consonant clusters?
3. How do children realise clusters before they have acquired adult-like production and are there any specific relationships between those patterns and correct production (trend 3 and 4)?
4. What developmental patterns of cluster acquisition can be observed over time (trend 5)?

Method

Participants

The data presented here originated from different studies. Firstly, data came from cross-sectional studies, including a total of 717 children aged 2;00-5;11 to investigate the phonological acquisition in German-speaking children. Data were collected during the years 1999-2012 in different urban and rural areas across Germany which included a range of different dialectal variations and children with different levels of socioeconomic status. The data for all children aged 2;00-2;11 (n = 145) were extracted from this data pool. Secondly, an eight months longitudinal study was conducted to explore cluster acquisition over time. Children aged 2;00-2;03 who attended a crèche in Hamburg, a city where standard German is spoken, were recruited. Their parents or carers were asked to provide consent for their children to participate in monthly testing sessions. Six children (2 girls and 4 boys) took part in the project.

To ensure that all children met the selection criteria, parents and carers were asked to complete a questionnaire about their children's language. Selection criteria were included as follows: monolingual German-speaking children, no history of speech and language difficulties, no significant hearing loss, no other physical / cognitive impairments. In addition, for all children who were tested in their nurseries, nursery staff were asked to confirm that those children were all typically developing.

Material

Two versions of the Psycholinguistische Analyse Kindlicher Aussprachestörungen (PLAKSS-II, Fox-Boyer, 2014; PLAKSS, Fox, 2005), a well-established picture naming test to assess phonetic and phonological skills in German-speaking children, were administered. The PLAKSS's qualitative and quantitative analysis provides an overview of the child's phonetic and phonemic inventory, including phonological processes. All German word-initial clusters (apart from /pl, pr, gn, ps, vʁ, pfʁ/ which rarely occur in young children's vocabulary) are included and tested by one or two items (a total of 99 test items). The PLAKSS-screening consists of 31 items with a reduced list of initial clusters. Hence, depending on the test version, children had different numbers of opportunities to produce clusters. The majority of children was assessed with the full version of the test, 34 were tested with the screening since they were part of a different study. Children were presented with the pictures one at a time and were asked to name them. When children were not able to independently name the picture, they were offered three cues in the following order: a cloze sentence (e.g. the farmer drives a…), alternative choices (e.g. is this a tractor or a ball?), or the children were asked to repeat the word.

Supplementary Materials Table I provides a list of all test items for both PLAKSS versions. Most of the items were mono- or bisyllabic. Apart from two items the cluster structure always occurred in word onset position which was also the stressed syllable of the word (exceptions: /kʁokoˈdiːl/, i.e. <crocodile>; /ˈ t͡sebʁa/, i.e. <zebra>). For 2 items the cluster structure occurred in the second, i.e. stressed, syllable (/gəˈʃpɛnst/, i.e. <ghost>, /t͡siˈtʁoːnə/ i.e. <lemon>). Few clusters were tested by two items. For those it was investigated to which extend children showed variable cluster productions. It was shown that in the younger group a mean of 81.03% and in the older group a mean of 83.55% of the children were consistent in their production.

Procedure

Speech assessments were carried out by qualified speech and language pathologists (SLPs) or trained final year SLP students in a quiet room within the nursery (76%) or at the children's home (24%). Parents or carers were allowed to attend the test session which lasted approximately 5-25 minutes depending on the attention and motivation level of the child and the test version administered. Broad online transcription was used by the testers during the assessment. All transcriptions were checked against audio-recordings (devices used: Sony Professional Micro Stereo recorder + Olympus W650S) following the test sessions. Experienced SLPs (not the testers) listened back to 10% of all recordings to determine inter-rater reliability. The inter-rater reliability was 98.3%.

Data analysis

Percentage of consonant clusters correct (PCCC) was calculated. To avoid a simple relational analysis of children's cluster production in comparison to adult-like realisations and to allow a more fine-grained qualitative analysis of developmental patterns, the following two PCCC-categories were defined: PCCCa was based on adult-like consonant cluster productions: This category included correct high standard German productions but also phonetic variations of /r/ productions (i.e. [ʁ̥] for [ʁ]), interdental realisations of /s/ and voicing changes ((de)voicing, e.g. [pʁot] instead of [bʁot], i.e. <bread>). (De)-voicing of consonant clusters occurs as dialectal variation in different regions across Germany. Additionally, as Macken and Barton (1980) and Ota & Green (2013) argue, phonetic boundaries for voicing differ in children in comparison to adult-like productions (see Ota & Green, 2013, p. 548). Phonetic variations, in particular lisps, were excluded since a high percentage of children show them up to the age of six (see Fox-Boyer, 2016). Moreover, in the German phoneme inventory interdental/lateral sounds (i.e. /θ, ð, ɬ/ versus /s, z, ʃ/) have allophonic status. PCCCp was based on cluster productions which are considered to be phonologically correct: Phonologically correct means that specific substitutions of one of the two elements of a cluster were accepted as correct forms. The substitutions accepted as phonologically correct were fronting of /k g/, fronting or backing of /ʃ/ (e.g. [slaŋə] or [çlaŋə] instead of /ʃlaŋə/, i.e. <snake>) and assimilations for /fl/ → [sl/ʃl] and /tʁ, dʁ/ → [kʁ gʁ] (e.g. [ʃlaʃə] instead of /flaʃə/, i.e. <bottle>; [gʁaxə] instead of /dʁaxə/, i.e. <dragon>; [kraktoɐ] instead of /tʁaktoɐ/, i.e. <tractor>). This was done for three reasons: firstly, these substitutions lead in the majority of cases to phonotactically illegal clusters for German and only rarely to minimal pairs. Secondly, the substitutions were caused by not yet acquired singletons, i.e. /k, g/ and /ʃ/, which are only acquired by many children after the age of three (Fox-Boyer, 2016). Thirdly, /θ, s/ and /z, ð/ are not phonologically contrastive in German.

In the cross-sectional data set, children were divided into two age groups, i.e. children aged 2;00-2;05 and 2;06-2;11. For each child, the number of CC(C)-words was counted and the number of cluster productions according to the two PCCC categories calculated. This led to two overall PCCC scores for each child. In addition, group PCCC mean scores for each cluster were computed (for the young and old group separately). Moreover, a qualitative analysis of substitution and reduction patterns was carried out. For the longitudinal study, PCCCs according to the two different categories were calculated per child per month. In addition to qualitative and descriptive analyses, inferential statistics were used to explore age effects (non-parametric correlations (Spearman) and group comparisons (Mann-Whitney-U-tests)).

Result

In order to answer how German-speaking children start producing clusters (research question 1) the PCCC for the two different sub-categories for both young and old 2-year olds was calculated (see Table II). Looking at the PCCC adult-like category (PCCCa), the younger 2-year olds produced on average 24% of all consonant clusters correctly. The older 2-year olds showed a percentage of over 55%. When accepting typical phonological processes (PCCCp), i.e. fronting and backing of /ʃ/, fronting of /k, g/ and assimilations, the younger ones showed a percentage of 40% cluster production, the older ones' percentage increased to almost 74%.

However, standard deviations and the score range for both groups showed a large variability in cluster production, some young children already showed a high number of correct clusters in contrast to some older children whose PCCCs were still considerably low. If age-appropriate phonological processes were accounted for, the majority of the older children were able to produce consonant clusters. The number of children who did not produce any clusters as categorised was very small (eight young children, two older children). Of those ten children eight children produced non-adult like clusters and only two children produced no clusters at all.

Table II about here

In order to explore age effects, non-parametric correlations (Spearman) were computed. Strong and statistically significant correlations were found between both PCCC-scores and age (PCCCa: r = .57, $p_{2\text{-tailed}} < 0.001$; PCCCp: r = .57, p_2-tailed < 0.001). Group comparisons were computed (Mann-Whitney-U-tests) which showed highly significant group differences, even after applying Bonferroni corrections. The older group outperformed the younger group as follows: PCCCa: U = 3,971.500, $N_1 = 55$, $N_2 = 90$, $p < 0.001$, r = 0.51; PCCCp: U = 3,911.000, $N_1 = 55$, $N_2 = 90$, $p < 0.001$, r = 0.49. In sum, 2-year-old children can produce clusters correctly, however the variability especially in the younger age group concerning PCCC is considerable.

The second research question addressed the order of acquisition (measured by different PCCC scores) for different clusters. Table III provides an overview of the percentage of adult-like productions for each cluster per age group.

Table III about here

For the younger children no initial cluster could be considered acquired, since all percentages remained below 75% (according to other studies, a cluster was considered as acquired when a PCCC of at least 75% was achieved, see e.g. Fox & Dodd, 1999; McLeod, Van Doorn, & Reed, 2001b). /kl/ and /gl/ were mostly produced correctly in both groups and in the older group those two clusters fulfilled the 75% criterion. The remaining non-/ʃ/-clusters had lower PCCCs, and /ʃ/-clusters had the lowest PCCCs, including the three-element /ʃ/-clusters.

However, this picture of /ʃ/-clusters being acquired later than non-/ʃ/-clusters changed when backing/fronting of /ʃ/ were accepted as correct. Hence, the percentage correct for /ʃ/-clusters increased significantly in both groups. A range of them were produced correctly at a similar level as the non-/ʃ/-clusters (see Table III: /ʃ/-clusters in bold and italics). Some of them reached an even higher level of PCCC in comparison to the non-/ʃ/-clusters. In sum, cluster composition did not impact on performance, 2- and 3-element clusters were acquired at a similar rate and clusters which include stops were not mastered before clusters with fricatives when backing/fronting of /ʃ/ was accepted.

In order to explore how children realise clusters before they have acquired adult-like productions and which specific relationships between those patterns and correct productions (research question 3) exist, an independent analysis was conducted. Concerning types of realisation patterns, it was found that German-speaking children only show cluster reductions and substitutions. Cluster deletion, coalescence and schwa-epenthesis were not found. Table IV and V provide an overview of patterns for all clusters across both age groups (see Supplementary Material Table II for an overview of the longitudinal data).

Table IV and V about here

The data can be summarised as follows:

When the first consonant of the cluster was a plosive or /f/ followed by /l/, both age groups reduced the cluster to either the first or second consonant. In the younger age-group, there was a preference for C_1 for /gl/and /kl/. In the older age group, there was a preference for C_2 for the cluster /kl/. However, it has to be noted that the overall number of children who reduced or showed a specific reduction pattern was very small.

Looking at clusters starting with a plosive or the fricative /f/ followed by /ʁ/, nearly all children of the younger age-group reduced the cluster to C_1. In the older age group, the children still preferred C_1 but some of the C_1C_2-structures were also reduced to the second consonant (i.e. C_2). The clusters /kv/ and /kn/ were most likely to be reduced to C_2 in both age-group.

For /ʃ/-clusters, a general preference for reducing C_1 was observed. However, reduction patterns for /ʃl/ are less clear and resemble those with non-/ʃ/+/l/ clusters, showing reductions to C_1 or C_2 respectively. Additionally, the cluster /ʃʁ/ follows the pattern of the non-/ʃ/ + /ʁ/ clusters, with a preference of C_1 in the younger or no preference in the older age-group.

The three element clusters /ʃpʁ/ and /ʃtʁ/ were preferably reduced to C_2 or, less often, to C_2C_3 in the younger group. In the older age-group, if /ʃtʁ/ and /ʃpʁ/ were reduced to one element, the most likely option was still C_2. The picture was less clear when only one element was reduced, any of the three options (C_1C_2, C_2 C_3, or C_1C_3) was observed.

As expected, the following types of substitution errors were found: fronting of /k/, /g/ and /ʃ/, backing of /ʃ/ and assimilation of /fl/ to [sl] and /dʁ/, /tʁ/ to [kʁ] [gʁ]. Stopping or gliding of /l/ and /r/ which are typical phonological processes for English speaking children were not found.

Some researchers (e.g. Dyson & Paden, 1983) suggest that children's cluster productions expose an interrelationship between cluster reductions, substitutions and correct productions, and different developmental sequences. Data for each individual cluster (see Table IV above) and group findings (see Table VI) illustrate those relationships.

Table VI about here

In the younger group, cluster reduction was more frequent than cluster substitution for the non-/ʃ/-clusters, the discrepancy was much smaller for the /ʃ/-clusters. Looking at substitutions, it seems at first that these occur nearly twice as often in /ʃ/-clusters than in non-/ʃ/-clusters. However, if specific substitution patterns are accepted as phonologically correct (as described above), the two types of clusters do not differ substantially. The picture is even clearer for the older group, where it seems that substitutions occur far more frequently than reductions. However, considering the phonologically correct criterion, this is not the case. The described patterns can also be found in the independent analysis of the longitudinal data (see Supplementary Materials, Table II).

The longitudinal study also provided the basis to explore which cluster acquisition patterns could be observed over time (research question 4). The data were analysed using the same PCCC-categories that were applied to the cross-sectional data. Each child showed a distinct profile (see figures I).

Figure I about here

For child 1 the differentiation between categories did not result in different developmental patterns. She started with rather high PCCCa / PCCCp scores and exhibited a large improvement in cluster production between 2;04 and 2;05, showing around 90% of adult-like cluster productions thereafter.

Child 2 showed distinct patterns depending on the PCCC-category. The acceptance of phonological processes increased her PCCCp considerably from the first testing point at the age of 2;04, reaching a PCCCp of around 90% at the end of the study when she was 2;11.

For Child 3 the PCCCp increased considerably in contrast to his PCCCa of adult-like productions. He showed a rather constant performance throughout the study but a significant increase in both categories at the last testing point when he was 2;11.

Child 4 showed a clear increase of her correct cluster productions when phonological processes were accepted. Over the first six months of the study he managed to continuously improve both scores, reaching a PCCCp of 100%. When only adult-like performance was accepted, his PCCCa score did not further improve after the age of 2;08.

For child 5 the analysis of PCCC-categories did not result in different PCCC scores for the first three months when he was between 2;01 and 2;04. Thereafter, a distinct increase in both categories could be observed with a very steep increase to almost 100% for the PCCCp.

Child 6 showed quantitative differences depending on the PCCC-category. Whereas his PCCCa increased slowly over time, the PCCCp increased distinctly between 2;03 and 2;04.

In sum, those six children showed that inter- and intra-individual developmental patterns can be observed and that those patterns change over time. Some children showed a more gradual development (e.g. child 4) and some a significant improvement at some point during the study (e.g.

child 3 between 2;10 and 2;11). Developmental patterns included reversals, i.e. a decrease of PCCC in comparison to earlier scores, and revisions, i.e. an increase of PCCC after a reversal (e.g. child 2). Moreover, the distinction of the different PCCC-categories showed for the majority of children that PCCC growth patterns diverged, showing much higher scores (for all children at the end of the study between 90-100% PCCC) when phonological processes were taken into account (PCCCp), confirming children's general ability to produce clusters. Concerning the question whether /ʃ/-clusters are acquired earlier or later, in line with cross-sectional data, the findings showed that /ʃ/-clusters were acquired at the same time as non-/ʃ/-clusters when fronting and backing of /ʃ/ were accepted as correct.

Discussion

Data from cross-sectional studies and one longitudinal study were analysed to explore onset cluster production in German-speaking 2-year olds. Results are discussed in relation to the research questions.

The first research question aimed to investigate how clusters develop in German-speaking children between the age of 2;00-2;11 when compared to adult-like productions but also when developmental phonological processes are considered. The current study confirmed the expected trend reported by McLeod et al. (2001a) as well as the results from studies on different languages (e.g. Hebrew: Bloch, 2011; Portuguese: Freitas, 2003; Dutch: Jongstra, 2003; French: MacLeod et al., 2011; English: McLeod et al., 2001a; German: Bartels, 2012) that 2-year olds are able to produce consonant clusters and that cluster production correlates with age. When fronting/backing or assimilations were accepted as phonologically correct productions (PCCCp), a procedure which has not been applied so far in the literature, higher percentages of correct cluster production were found for the category. This was specifically true for /ʃ/-clusters, where the typical fronting or backing of the singleton /ʃ/ was observed within the cluster. These substantially higher PCCC scores indicate already stable cluster productions in general. This underlines the importance to differentiate children's performance and to account for typical phonological processes. It also shows that children can expressively produce 2- and 3-element clusters despite prevailing phonological processes, even when the use of substitutions results in clusters violating phonotactic rules in German (e.g. /ʃlaŋə/ → [slaŋə]). Hence, phonological and phonotactic constraints do not seem to prevent children from learning speech motor patterns with complex onset constructions.

The second question addressed the order of acquisition (measured by PCCC scores) for different clusters in German. Despite the significant increase of cluster production over time, only /gl/ and /kl/ were shown to be phonetically and phonemically acquired in the older age-group (see 75% criterion, e.g. Fox & Dodd, 1999). These findings are in line with findings on French which showed that /bl/ had reached the 75% threshold at the same age, followed by /fl/ half a year later (MacLeod et al., 2011). This very early onset of cluster acquisition contradicts English findings which identified the onset of cluster acquisition for /tw/ and /kw/ at the age of 3;06 years, followed at 4;00 by /pl/, /bl/, and /kl/ (Smit, Hand, Freilinger, Bernthal, & Bird, 1990). Hence, the findings from those three languages indicate that clusters with /l/ are acquired first, irrespective of the other cluster element being a fricative or plosive.

Previous research had found mixed results for the acquisition of /s/-clusters. While earlier findings, e.g. reported by Smit (1993), assumed that /s/-clusters are acquired later than non-/s/-clusters, McLeod et al. (2001a) stated that /s/-clusters were produced most correctly in their datasets. Findings of the current study supported both arguments depending on whether fronting and backing of /ʃ/ were accepted. When only adult-like productions were considered /ʃ/-clusters were acquired later in comparison to non-/ʃ/-clusters. However, when fronting and backing of /ʃ/ were allowed /ʃ/-clusters were acquired at the same time or even earlier than other clusters. The clusters /ʃm/, /ʃl/, /ʃn/, /ʃv/, /ʃʁ/, and /ʃp/ reached percentages above 75% between 2;06-2;11 years. This is in line with research arguing that both cluster groups are acquired at the same rate (Sanoudaki, 2008). This might be due to the high frequency of words containing /ʃ/-clusters in the children’s vocabulary and in child directed speech. In addition, /ʃ/-clusters comprising of /ʃ/+stop (i.e. /ʃt/ and /ʃp/) which violate the Sonority Sequencing Principle were acquired at the same rate as other /ʃ/-clusters such as /ʃm/.

The assumption that markedness based on sonority distance impact on the acquisition of clusters could be confirmed for the two clusters the older group acquired first (i.e. /gl/, /kl/). Based on Hogg and McCully's (1987) sonority scale the distance between both consonants is four or five respectively. However, the other clusters did not follow this principle. For example, in both age groups /dʁ/ and /kn/ were acquired at the same time despite their diverging sonority difference (2 and 4 respectively). Hence, sonority principles do not fully explain the order of cluster acquisition in German which is in line with data from other languages (for example Polish, see Yavaş & Marecka, 2014).

The current study also addressed the question whether 2-element clusters are acquired before 3-element clusters. The data revealed that 3-element clusters were acquired at the same rate as 2-element clusters which contradicts McLeod et al.'s (2001a) trend that 2-element clusters are acquired prior to 3-element clusters and provides some evidence that phonotactic complexity may not necessarily impact on cluster production. On the other hand, there are less 3-element clusters to be acquired in German (i.e. /ʃpʁ, ʃtʁ/) than in English (4) However, French includes five 3-element clusters but similar to German findings on French showed no difference in the acquisition of /skɥ/ in comparison to 2-element clusters (MacLeod et al., 2011). The early acquisition of the 3-element clusters might be influenced by the high lexical frequency of words with /ʃpʁ/ and /ʃtʁ/ in child directed speech as suggested by data from Ota & Green (2013).

Children who produce words that include initial clusters realise these in different ways. Cluster reduction and substitution have been claimed to be the most common pattern (e.g. MacLeod et al., 2011; McLeod et al., 2001a; Smit, 1993). Within these pattern clusters behave differently as to the types of substitutions of the elements to be reduced. Research question three investigated the realisation patterns in German-speaking children and whether any specific relationships between those patterns and correct production exist. Results from the current study indicated that cluster reduction and cluster substitutions were found, which is in agreement with findings on English (Smit, 1993) and French (MacLeod et al., 2011). However, additional patterns such as epenthesis, metathesis or coalescence which were described by Chin & Dinnsen (1992) were not found. In very rare occasions a cluster was deleted.

For an in-depth understanding of reduction patterns, which may be relevant for clinical decision making, a qualitative analysis of the data was conducted. It revealed different reduction patterns as a function of both age and type of cluster. In both age groups, clusters containing a plosive or /f/ followed by /l/ were either reduced to C_1 or C_2. This finding is not in line with results reported for other languages where C_1 is generally described to be the remaining consonant (Spanish: Barlow, 2003; Portuguese: Freitas, 2003; Dutch: Jongstra, 2003; English: Smit, 1993). However, in Hebrew there seems to be a preference for C_2 (Forkush, 1997 as cited in McLeod, 2013). Hence, for those clusters cross-linguistic differences are observable and data do not clearly support the sonority principle. A clearer picture arose for the C+/ʁ/-clusters, C_1 was preferred by the majority of children. This is in accordance with the languages mentioned above (except Hebrew: Ben-David & Berman, 2007) and studies on French (Demuth & McCoullough, 2009; MacLeod & Findlay, personal communication, December 2015). Generally, those results are in line with the sonority principle, assuming that the less sonorous consonant is kept. For /ʃ/-clusters findings showed a preference for C_2 which supported data from other languages (see references above). However, similar to findings on Dutch (Jongstra, 2003), a slight preference of C_1 over C_2 in /ʃ/-clusters containing /l/ or /ʁ/ was found. For a theoretical discussion on these clusters, please see Yavaş, Fox-Boyer & Schaefer (2016).

German-speaking children showed only few substitutions of phonemes, as had been expected. Fronting of /k g/ and /ʃ/ have also been reported by Smit (1993) for English and by MacLeod & Findlay (in preparation) for French. Assimilation of /dʁ, tʁ/ to /gʁ, kʁ/ are also described as typical for French by MacLeod & Findlay (in preparation). For English however, a very common substitution was gliding of /l/ and /r/, which is neither common for German nor French. This pattern could be a reason for the later acquisition of clusters in English.

Concerning the question of specific developmental relationships between the realisation patterns, the quantitative findings from the younger group argue for the trend that younger children produce more non-/ʃ/-cluster reductions than substitutions. A high number of non-/ʃ/-productions in the older group were produced correctly, supporting Dyson and Paden's (1983) first pattern (i.e. cluster reduction → correct), this was underpinned by the longitudinal data. Nevertheless, results also showed that this effect was less strong for the /ʃ/-clusters, emphasising that it is important to consider the whole cluster inventory and not only a selection of clusters. For the /ʃ/-clusters in the younger group, the number of substitutions was much higher than for the non-/ʃ/-clusters, in the older age group the number was even higher. Thus, the second pattern seems to be more applicable (i.e. cluster reduction → substitution → correct), However, two things have to be noted: a) that the substitution of /ʃ/-clusters was due to the fact that the children had not yet acquired the phoneme /ʃ/ and b) data from the longitudinal study were less clear. Thus it can be claimed that for German speaking children the main acquisition trend is from cluster reduction to correct realisations. Support for Dyson and Paden's (1983) third pattern, which includes null realisations, were not found in the current study.

The final trend addressed in the current study was the assumption that cluster development shows variability over time. This aspect was strongly supported by McLeod and colleagues (2001a) and underpinned by data from the longitudinal study of German speaking children presented here. Results showed distinct inter- and intra-individual differences, confirming that speech acquisition in the early years is not linear and marked by variability (Schaefer & Fox, 2006; Vogel Sosa & Stoel-Gammon, 2006) which includes consonant clusters (McLeod et al., 2001a; Sanoudaki, 2008). Hence, group results may show a significant increase of PCCC over time, but individual children may show unimproved PCCC scores for several months before exhibiting a steep increase. Alternatively, some children may demonstrate a rather gradual increase of cluster production including slight decreases of

PCCC (probably due to still instable cluster productions) before PCCC continues to increase. Clinical implications include that for this age group no fixed or typical cluster acquisition process can be assumed. Thus, SLPs need to consider other speech measures to detect atypical speech acquisition at this age in order to decide which child is in need for intervention. In addition, the use of different PCCC-categories indicates that the majority of children exhibited a substantial increase in PCCC when phonetic and phonological processes were accounted for. Thus, it might be helpful to use different PCCC-categories in order to evaluate a child's speech. If children are able to generally produce clusters (despite using phonetic/phonological processes), interventions may not need to focus on cluster production.

Limitation

Different versions of the speech assessment PLAKSS were used, resulting in a varied number of cluster productions across all children. In addition, to calculate PCCC scores for each cluster, only one utterance per cluster was used. Since specifically children up to the age of 2;05 are highly variable in their speech production (e.g. Schaefer & Fox, 2006), this procedure is debatable. It would be beneficial for further studies to collect data based on a consistent number of items, including several productions of the same cluster types. In addition, children from the longitudinal study could not be followed up to explore who may have shown phonological delays or disorders in the long-term and to identify potential clinical markers (Perry Carson, Klee, Carson, & Hime, 2003).

Conclusion

The paper presented the first comprehensive data analysis of a large dataset on consonant cluster acquisition in German-speaking 2-year olds. It included cross-sectional and longitudinal data which allowed to explore group trends and individual acquisition patterns. Findings supported that 2-year olds are able to produce consonant clusters and that cluster acquisition improves significantly with age. However, age of acquisition (75% criteria) was only reached for a few clusters. The application of different PCCC proved to be useful, showing that when phonetic and phonological processes are accounted for, children achieve a considerably higher PCCC, including /ʃ/-clusters. Longitudinal data showed diverse patterns, confirming intra- and inter-individual variability. However, by the end of the study all children showed a considerable increase of PCCC, which supports the notion that at the age of three children should be able to produce clusters. Concerning developmental sequences, it was observed that younger 2-year-olds produced more reductions than simplifications. The older 2-year-olds produced more simplifications for the /ʃ/-clusters, due to the fact that the phoneme /ʃ/ had not been acquired.

Although clusters are commonly not addressed in speech intervention for two year olds, the knowledge about how children realise and acquire clusters at an early age provides a baseline on which cluster realisations in older children with speech disorders can be evaluated. Children with speech sound disorders might follow a developmental age-appropriate or delayed path, but they may also show deviant realisation patterns. Different intervention approaches might be necessary (Fox-Boyer & Neumann, 2016).

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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Table I: Word initial clusters in English, German and French

Cluster type	English*	German**	French***
Stop + liquid /l/	pl bl kl gl	pl bl kl gl	pl bl kl gl
Stop + liquid /ɹ/	pr br tr dr kr gr	pʁ bʁ tʁ dʁ kʁ gʁ	pʁ bʁ tʁ dʁ kʁ gʁ
/f/ + /l/	fl	fl	fl
Fricative + /ɹ/ʁ/	fr θr	fʁ	fʁ vʁ
Stop + nasal / fricative		kn kv	ps
Possibly adjunct consonant cluster			
/s/ ʃ/+ stop	sp st sk	ʃt ʃp	sp st sk
/s/ ʃ/+ nasal	sn sm	ʃn ʃm	
/s/ ʃ/+ /ɹ/ʁ/	ʃr	ʃʁ	
/s/ ʃ/+ /l/	sl	ʃl	
/s/ ʃ/+/w/ or /v/	sw	ʃv	sw sj ʃw ʃj
/s/+ stop + liquid	spl spr str skr	ʃpʁ ʃtʁ	spl spʁ stʁ skl skʁ
Either true cluster or rising diphthong			
Stop + glide	pw pj bj tw tj dw dj kw kj gw		pw pj pɥ bw tw dw tj dj kɥ
Nasal + glide	mj nj		mw mj nj
Fricative + glide	fj vj θw		hɥ
Stop + fricative + glide			bʁɥ, dʁw, tʁw

Note. * English and *** French, Rvachew, Leroux & Brosseau-Lapré (2014), ** German, Wiese (1996)

Table II: Percentage consonant clusters correct (PCCC) for both young and old 2-year olds

	2;00-2;05 (n=55)				2;06-2;11 (n=90)			
PCCC categories	Mean	SD	Min	Max	Mean	SD	Min	Max
PCCCa[1]	23.67	21.35	0	88	55.19	30.14	0	100
PCCCp[2]	40.31	33.01	0	96	73.82	30.63	0	100

Note. [1] Adult-like productions: including (de)voicing/phonetic variations;
[2] adult-like productions and not accounting for fronting of /k, g/, fronting or backing of /ʃ/, or assimilations.

Table III: Percentage of adult-like productions for German initial clusters according to age groups, with italics and bold font indicating percentage consonant clusters correct when accounting for backing/fronting of /ʃ/

Percentage correct	**2;00-2;05**	**2;06-2;11**
0-9%	ʃp ʃʁ ʃt ʃn ʃv ʃl ʃm ʃtʁ ʃpʁ	
10-19%		
20-29%	bl bʁ fl dʁ kn kʁ kv ***ʃtʁ***	
30-39%	fʁ tʁ gl gʁ ***ʃm ʃpʁ***	ʃp ʃʁ ʃt ʃn ʃv ʃl ʃm ʃtʁ ʃpʁ
40-49%	kl ***ʃʁ ʃp***	
50-59%	***ʃl ʃn ʃv ʃt***	fl fʁ dʁ gʁ kn ***ʃpʁ***
60-69%		bl bʁ tʁ kʁ kv ***ʃtʁ ʃt***
70-79%		gl ***ʃm ʃv ʃʁ ʃp***
80-89%		kl ***ʃn ʃl***
90-100%		

Note. All children who showed backing/fronting of /ʃ/-clusters also fronted or backed /ʃ/-singletons.

Table IV: Cluster realisation patterns in 2-year olds: percentages and numbers of children showing reductions, substitution and substitutions excluding defined processes, including percentages and numbers of specific reduction or substitution pattern

	Target	Cluster reduction % (n)	Children reducing a CC to either C_1 or C_2* % (n)						Substitu-tions to C1 or C2 % (n)	Children showing specific substitutions* % (n)		Substitu-tions excl. processes % **
			to C_1				to C_2					
2;00-2;05	**bl**	53 (21)	**b/p**	48 (10)			**l**	38 (8)	8 (3)			
	gl	39 (15)	**g/k**	27 (4)	**d/**	33 (5)	**l**	33 (5)	8 (3)	**dl/tl**	67 (2)	3
	kl	38 (13)	**k/g**	23 (3)	**t/**	31 (4)	**l**	23 (3)	6 (2)			
	fl	57 (30)	**f/v**	39 (12)			**l**	32 (10)	21 (11)	**sl/çl**	82 (9)	4
	bʁ	54 (21)	**b/p**	91 (19)			**ʁ**	0 (0)	3 (1)			
	gʁ	43 (15)	**g/k**	86 (12)	**d/**	14 (2)	**ʁ**	0 (0)	11 (4)	**dʁ**	50 (2)	6
	kʁ	69 (31)	**k/g**	31 (10)	**t/**	56 (18)	**ʁ**	3 (1)	9 (4)	**dʁ/tʁ**	75 (3)	2
	dʁ	44 (23)	**d/t**	64 (16)	**g**	20 (5)	**ʁ**	14 (1)	21 (11)	**gʁ/kʁ**	82 (9)	6
	tʁ	52 (28)	**t/d**	82 (23)	**g**	7 (2)	**ʁ**	4 (1)	14 (7)	**kʁ**	100 (7)	0
	fʁ	53 (20)	**f/v**	75 (15)			**ʁ**	15 (3)	11 (4)			
	kn	68 (34)	**k**	6 (2)	**t/**	15 (5)	**n**	74 (24)	12 (6)			
	kv	69 (22)	**u**	14 (3)	**b/**	27 (6)	**f/v**	45 (10)	9 (3)			
	ʃl	44 (23)	**s/ç**	30 (7)			**l**	54 (9)	52 (27)	**sl/çl**	100 (27)	0
	ʃm	62 (31)	**s/ç**	6 (2)			**m**	77 (24)	30 (15)	**sm/çm**	93 (14)	2
	ʃn	47 (17)	**s/ç**	18 (3)			**n**	76 (13)	42 (15)	**sn/çn**	100 (15)	0
	ʃʁ	46 (15)	**s/ç**	41 (7)	**d**	29 (5)	**ʁ**	12 (2)	45 (15)	**sʁ/çʁ**	73 (11)	12
	ʃv	42 (15)	**s/ç**	7 (1)			**f/v**	77 (10)	53 (19)	**sv/çv**	84 (16)	8
	ʃt	48 (23)	**s/ç**	24 (7)			**t/d**	72 (21)	48 (23)	**s/ç, t/d**	100 (23)	0
	ʃp	56 (28)	**s/ç**	4 (1)			**p/**	93 (25)	40 (20)	**s/ç, p/b**	100 (20)	0
2;06-2;11	**bl**	12 (9)	**b**	44 (4)			**l**	33 (3)	5 (4)			
	gl	15 (11)	**g/k**	0 (0)	**d/**	27 (3)	**l**	45 (5)	3 (2)	**dl**	17(1)	1
	kl	8 (6)	**k/g**	0 (0)	**t/**	17 (1)	**l**	83 (5)	1 (1)			
	fl	19 (17)	**f/v**	41(7)			**l**	35 (6)	25 (22)	**sl/çl**	83 (19)	3

bʁ	21 (16)	b/p	75 (12)			ʁ	13 (2)	1 (1)			
gʁ	21 (16)	g/k	50 (8)	d	6 (1)	ʁ	31 (5)	8 (6)	dʁ	83 (5)	1
kʁ	29 (24)	k/g	54 (13)	t/	38 (9)	ʁ	8 (2)	4 (3)	dʁ/tʁ	100 (3)	0
dʁ	20 (18)	d/t	56 (10)			ʁ	39 (7)	15 (13)	gʁ/kʁ	92 (12)	1
tʁ	24 (21)	t/d	38 (8)	g	19 (4)	ʁ	38 (8)	11 (10)	kʁ	90 (9)	1
fʁ	26 (20)	f/v	55 (11)			ʁ	40 (8)	9 (7)	çʁ	71 (5)	3
kn	29 (25)	k	8 (2)	t/	12 (3)	n	76 (19)	9 (8)	tn	13 (1)	9
kv	31 (23)					v/	65 (15)	3 (2)			
ʃl	14 (12)	s/ç	47 (8)			l	35 (6)	55 (49)	sl/çl	96 (47)	2
ʃm	20 (17)	s/ç	0 (0)			m	89 (16)	44 (38)	sm/çm	95 (36)	3
ʃn	14 (11)	s/ç	9 (1)			n	91 (10)	48 (37)	sn/çn	95 (35)	3
ʃʁ	21 (15)	s/ç	47 (7)			ʁ	47 (7)	39 (27)	sʁ/çʁ	89 (24)	4
ʃv	25 (19)	s/ç	15 (3)			f/v	80 (16)	36 (27)	sv/çv	89 (24)	4
ʃt	24 (21)	s/ç	15 (4)			t/d	69 (18)	43 (37)	s/ç, t/d	97 (36)	1
ʃp	25 (22)	s/ç	0 (0)			p/	91 (20)	44 (39)	s/ç, p/b	98 (40)	1

Note. * The percentages were calculated as follows: n children showing reductions/substitutions = 100%. In all cases when the percentages of the reductions or substitutions do not add up to 100%, 1 to max. 4 children showed further reduction patterns, which could not be classified; ** the percentages presented are those when the PCCCp conditions were accepted as phonologically correct.

Table V: Cluster realisation patterns for 3-element clusters in 2-year olds

			% of children reducing a CCC to either C_1, C_2 or C_3*									% of children reducing a CCC to CC*								
	Target	**% of children reducing CCC to C**	C_1	%	C_2	%	C_2	%	C_3	%	**% of children reducing a CCC to CC**	C_1C_2	%	C_2C_3	%	C_1C_3	%	**% of children substituting CCC****	$C_1C_2C_3$	%
2;00-2;05	**ʃpʁ**	58	**s/ç**	4	**p/b**	70			**ʁ**	4	36	**s/ç, p/b**	0	**p/b, ʁ**	100	**s/ç, ʁ**	0	24	**s/ç, p/b, ʁ**	100
	ʃtʁ	41	**s/ç**	8	**t/d**	54	**k/g**	15	**ʁ**	15	34	**s/ç , t/d**	36	**t/d, (k)**	36	**s/ç, ʁ**	27	16	**s/ç, t/d, ʁ**	75
2;06-2;11	**ʃpʁ**	16	**s/ç**	0	**p/b**	75			**ʁ**	25	20	**s/ç , p/b**	30	**p/b, ʁ**	35	**s/ç, ʁ**	10	27	**s/ç, p/b, ʁ**	95
	ʃtʁ	7	**s/ç**	0	**t/d**	60			**ʁ**	40	21	**s/ç, t/d**	19	**t/d, (k)**	38	**s/ç, ʁ**	44	29	**s/ç, t/d, ʁ**	86

Note. * The percentages were calculated as follows: N children showing reductions/substitutions = 100%. In all cases when the percentages of the reductions or substitutions do not add up to 100%, 1 to max. 4 children showed further reduction patterns, which could not be classified.

Table VI: Mean percentage (SD) of non-/ʃ/- and /ʃ/-cluster realisations for children aged 2;00-2;05 and 2;06-2;11 concerning reductions and substitutions

	2;00-2;05		2;06-2;11	
	Non-/ʃ/ cluster	/ʃ/-cluster	Non-/ʃ/ cluster	/ʃ/-cluster
Reductions	52.83 (11.34)	48.65 (7.17)	21.15 (7.09)	20.28 (4.72)
Substitutions	18.46 (6.97)	44.25 (7.90)	13.58 (8.02)	44.04 (6.35)
Substitutions without processes	6.25 (3.60)	3.20 (4.96)	3.55 (3.83)	1.94 (1.37)

Figure I capture: The figure depicts the Percentage Consonant Clusters Correct (PCCC) over time for the six children who participated in the longitudinal study (read left to right). The dotted lines represent the Percentage Consonant Clusters Correct based on adult-like productions (PCCCa). The solid lines represent the PCCC including productions which are considered to be phonologically correct (PCCCp, see data analysis for a more details).