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

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

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### 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.

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## 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.

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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**

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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.

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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,

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2 but do not assess the full range of cluster productions and acquisition patterns (e.g. Barlow, 2003 for  
3 an overview of Spanish-speaking children; Demuth & McCullough, 2009 reporting longitudinal data  
4 on 2 French-speaking children or Yavaş, 2013 comparing data from six different languages; for a  
5 comprehensive overview of normative data across languages see McLeod, 2007). Therefore, the study  
6 by McLeod, Van Doorn, and Reed (2001a) provided key research in applying a mixed-method  
7 approach, i.e. including a longitudinal and cross-sectional design, to explore cluster acquisition in  
8 sixteen 2-year old English-speaking children. Their data were discussed in the context of previous  
9 research and theoretical assumptions, addressing a wide range of aspects and summarising essential  
10 trends in cluster acquisition. In the following, five of the trends which are relevant for the current  
11 study are described and discussed in the context of current research.  
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24 Firstly, English-speaking 2-year olds are able to produce consonant clusters and their  
25 correctness in production increases over time (see also Dodd, 1995; Dyson, 1988; Ota & Green, 2013;  
26 Stoel-Gammon, 1987). This finding is supported by McLeod, van Doorn and Reed (2001a). However,  
27 they found that some cluster realisations were not adult-like productions and sometimes even violated  
28 the language's phonotactic rules (for English e.g. [bwdɛd] instead of /brɛd/ or [fwɔŋ] instead of  
29 /frɔŋ/). They further observed adult-like realisations of clusters but also cluster reductions and  
30 substitutions in all their participants. This highlights the need to differentiate between different  
31 quantitative and qualitative measures to describe cluster acquisition, and to look at adult- and non-  
32 adult-like productions alike.  
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44 Concerning the age of acquisition (i.e. 75% of the children of one age group produced  
45 clusters correctly) McLeod (2013) reports in her literature summary that in English cluster acquisition  
46 only starts at the age around 3;06. In contrast, findings for Canadian French (MacLeod et al., 2011)  
47 show that customary cluster production (customary defined as at least 50% of children produce  
48 clusters correctly) begins between the age of 2;00 and 2;05 with the production of /bl/ /fl/ and /bw/.  
49 The cluster /bl/ was found to be acquired between the age of 2;06-2;11. Customary cluster production  
50 continues to increase during the age of 2;06-2;11 with the realisation of /fʋ/, /kʋ/, /pw/, /tr/ and /vj/.  
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2 Secondly, cluster composition impacts on when clusters are acquired: a) consonant clusters  
3 including stops are mastered before consonant clusters including fricatives (e.g. Templin, 1957). This  
4 assumption was not confirmed by McLeod et al. (2001a). Children in their cohort did not produce  
5 stop-clusters more correctly. b) two-element clusters are acquired before three-element clusters (e.g.  
6 Smit, 1993). McLeod et al. (2001a) found supporting evidence for this assumption although the  
7 overall number of elicited three-element clusters was small. In contrast, MacLeod et al. (2011)  
8 showed that French-speaking children acquired the only 3-element cluster they assessed (i.e. /skʷ/) at  
9 the same time as 2-element clusters.  
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12 Thirdly, different types of non-adult like realisation patterns can be found in children's  
13 developing phonology. Chin & Dinnsen (1992) described a large range of cluster realisation patterns  
14 for English-speaking children: a) cluster reduction, b) cluster substitutions, c) cluster deletion, d)  
15 coalescence (i.e. a single phoneme is produced which includes phonetic features from the adult  
16 cluster, e.g. /swɪm/ realised as [fɪm]), or e) production of schwa-epenthesis (i.e. /ə/ is added to a  
17 cluster, e.g. /flaɪ/ is realised as [fəlaɪ]). Findings by Smit (1993) indicated that the majority of their  
18 American English-speaking children showed cluster reductions and cluster substitutions. Cluster  
19 deletion was described as very rare and epenthesis was only mentioned for word final clusters.  
20 Coalescence was not explicitly described. The findings by McLeod et al. (2001a) on Australian  
21 children are in agreement with Smit (1993). In addition to the general realisation types Smit (1993)  
22 analysed patterns per cluster. Her findings showed that clusters containing an obstruent and either /l/  
23 or /r/ tended to be reduced to the obstruent. Only young 2-year olds occasionally retained the /r/. For  
24 substitutions frequent gliding of /l/ and /r/ to [w] was observed. For /s/-clusters, the /s/ tended to be  
25 deleted and reduction of /s/-clusters was observed longer than for other clusters. Demuth &  
26 McCullough (2009) analysed data from two French-speaking children. For clusters consisting of an  
27 obstruent + /ʁ/ there was a dominance for retaining the obstruent. This is in agreement with findings  
28 from MacLeod & Findlay (in preparation).  
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2 Fourthly, there is a relationship between cluster reductions, substitutions and correct  
3 productions. For example, Dyson and Paden (1983) suggested three potential production patterns:  
4 either a) cluster reductions are followed by correct productions, b) cluster reductions are followed by  
5 substitutions and lastly by correct productions, or c) cluster deletions are followed by cluster  
6 reductions, substitutions and correct production. In addition, younger children produce more cluster  
7 reductions than older children. When reductions decrease, an increase of substitutions can be  
8 observed. McLeod et al.'s (2001a) cross-sectional data confirmed this trend. However, their  
9 longitudinal data showed a less clear pattern and only partly underpinned developmental sequences  
10 suggested by Dyson & Paden (1983).  
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22 Finally, cluster development over time shows variability: distinct acquisition patterns can be  
23 found for children. Not all children exhibit a linear increase of correct cluster productions;  
24 developmental patterns are often characterised by reversals and revisions. This aspect was strongly  
25 supported by McLeod and colleagues (2001a).  
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### 31 **Consonant clusters in German**

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33 Comparable to English and French, German onsets can comprise a single consonant or a  
34 cluster with up to three consonants. A comparison between German and French cluster production is  
35 of interest, since French is one of the few languages with the same <r> realisation as German (i.e. /ʀ/).  
36 In addition, it is the only language with published data on clusters containing /ʀ/. The High German  
37 cluster system includes 23 2-element clusters in word initial position and two 3-element clusters,  
38 which can be found in childhood vocabulary (Wiese, 1996, for an overview see Table 1).  
39 Additionally, clusters such as /tʃv, ps, gn, vʁ, pʃʁ/ exist only in adult words which children do not  
40 recognise lexically at this age (Wiese, 1996) and were therefore excluded in the presented study  
41 design. Generally, as highlighted by Ota and Green (2013) those lexical constraints might impact on  
42 cluster acquisition.  
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57 Table I about here  
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2 The three systems show a high degree of similarity but a key difference is the occurrence of  
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4 /s/-clusters in English and French, which violate German phonotactic constraints, and /ʃ/-clusters in  
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6 German, with only two /ʃ/-clusters in either English or French. /s/-clusters have been proposed to  
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8 exhibit a special status, with /s/ syllabified outside the onset of the syllable to form an adjunct cluster  
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10 (Barlow, 2001; Yavaş, 2013). This assumption is also discussed for German /ʃ/-clusters (Bartels,  
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12 2012; Ott, Van De Vijver, & Höhle, 2006; Wiese, 1996). However, it is debated whether all /ʃ/- and  
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14 /s/-clusters need to be considered adjunct clusters or only those which are in conflict with sonority  
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16 principles (see e.g. Fikkert, 1994; Goad & Rose, 2009; Hall, 2000). For a more in-depth theoretical  
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18 discussion on /ʃ/- cluster acquisition in German see Yavaş, Fox-Boyer, and Schaefer (in preparation).  
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**Consonant cluster acquisition in German-speaking 2-year olds**

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27 The first researchers to document cluster acquisition in German-speaking typically  
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29 developing toddlers (2 girls, 3 boys) were Lleó and Prinz (1996), focussing on the clusters /fl/ and /fɪ/  
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31 or stop + /ɪ/. Results showed that up to the age of 2;01 years the children were not able to produce the  
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33 two clusters correctly but reduced these to the first element stop or /f/, thus following the sonority  
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35 principle, i.e. deleting the more sonorous element of the cluster. Fox and Dodd (1999) assessed cluster  
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37 acquisition in 180 children aged 1;06 – 5;11 within a cross-sectional study. Children were divided into  
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39 6-months age bands. Even though the children of the youngest age group already produced some  
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41 clusters, only at the age of 3;05 some clusters were acquired (75% criterion, see Dodd, 1995) and at  
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43 4;00 years mastered (90% criterion). The analysis of reduction patterns indicated that clusters  
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45 containing stops or /f/ followed by /ɪ/ were reduced mostly to their first element, which is in line with  
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47 the sonority principle. In contrast, clusters containing stops or /f/ followed by /l/ were reduced either  
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49 to their first or second element. Clusters containing /ʃ/ + a second consonant (C<sub>2</sub>) were reduced to C<sub>2</sub>,  
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51 not following the sonority principle. Clusters containing /ʃ/ + /p/ or /t/ + /ɪ/ were reduced to either  
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53 their third consonant (C<sub>3</sub>) or to C<sub>2</sub>C<sub>3</sub>. Piske (2001) observed speech production in very early  
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55 utterances of two children aged 0;11 and 2;03 years. Child 1 did not produce any clusters correctly but  
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2 reduced them all. Child 2 started realising clusters, but produced mainly phonotactically inadmissible  
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4 clusters such as /çl/ and /kç/. Bartels (2012) assessed cluster acquisition in six children aged 2;02-2;04  
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6 over 4 months. She found that all children but one produced a high number of non-/f/-clusters already  
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8 correctly at baseline (T1). At the end of the study (T5) four children produced all non-/f/-clusters  
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10 correctly and two children produced 65% of clusters correctly. The majority of /f/-clusters were  
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12 simplified by all but one child at T1. At T5 five children produced all /f/-clusters correctly, when  
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14 fronting or backing of /f/ was accepted as correct.  
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18 In sum, the empirical evidence base for word-initial cluster acquisition in German-speaking  
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20 children is still incomplete, based on small sets of data or datasets spread across a wide age range, and  
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22 not unanimous in supporting theoretical assumptions such as the sonority principle. Therefore, the aim  
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24 was to use large datasets from different cross-sectional studies and one short-term longitudinal study,  
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26 to explore acquisition patterns in German and compare them with English (Chin & Dinnsen, 1992;  
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28 McLeod et al., 2001a; Smit, 1993) and French (Demuth & McCullough, 2009; MacLeod et al., 2011).  
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30 The following research questions were addressed:  
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- 33 1. How do clusters develop in German-speaking children between the age of 2;00-2;11 when  
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35 compared to adult-like productions but also when reduction and substitution patterns are  
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37 considered (trend 1)?  
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- 40 2. What is the order of acquisition (measured by PCCC scores) for different clusters in German  
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42 (trend 2)?
  - 43 a. Are /f/-clusters acquired later in comparison to other German consonant clusters?  
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  - 45 b. Are 2-element consonant clusters acquired before 3-element consonant clusters?  
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- 48 3. How do children realise clusters before they have acquired adult-like production and are there any  
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50 specific relationships between those patterns and correct production (trend 3 and 4)?  
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- 53 4. What developmental patterns of cluster acquisition can be observed over time (trend 5)?  
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## 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, pʁʁ/ 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

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1  
2 initial clusters. Hence, depending on the test version, children had different numbers of opportunities  
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4 to produce clusters. The majority of children was assessed with the full version of the test, 34 were  
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6 tested with the screening since they were part of a different study. Children were presented with the  
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8 pictures one at a time and were asked to name them. When children were not able to independently  
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10 name the picture, they were offered three cues in the following order: a cloze sentence (e.g. the  
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12 farmer drives a...), alternative choices (e.g. is this a tractor or a ball?), or the children were asked to  
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14 repeat the word.  
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18 Supplementary Materials Table I provides a list of all test items for both PLAKSS versions.  
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20 Most of the items were mono- or bisyllabic. Apart from two items the cluster structure always  
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22 occurred in word onset position which was also the stressed syllable of the word (exceptions:  
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24 /kʁoko'di:l/, i.e. <crocodile>; /'tʃebʁa/, i.e. <zebra>). For 2 items the cluster structure occurred in the  
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26 second, i.e. stressed, syllable (/gə'ʃpɛnst/, i.e. <ghost>, /tʃi'tʁo:nə/ i.e. <lemon>). Few clusters were  
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28 tested by two items. For those it was investigated to which extent children showed variable cluster  
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30 productions. It was shown that in the younger group a mean of 81.03% and in the older group a mean  
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32 of 83.55% of the children were consistent in their production.  
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### 39 Procedure

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41 Speech assessments were carried out by qualified speech and language pathologists (SLPs)  
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43 or trained final year SLP students in a quiet room within the nursery (76%) or at the children's home  
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45 (24%). Parents or carers were allowed to attend the test session which lasted approximately 5-25  
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47 minutes depending on the attention and motivation level of the child and the test version administered.  
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49 Broad online transcription was used by the testers during the assessment. All transcriptions were  
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51 checked against audio-recordings (devices used: Sony Professional Micro Stereo recorder + Olympus  
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53 W650S) following the test sessions. Experienced SLPs (not the testers) listened back to 10% of all  
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55 recordings to determine inter-rater reliability. The inter-rater reliability was 98.3%.  
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## 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: PCCC<sub>a</sub> 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. [ʁ] for [ʀ]), 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, ʎ/ versus /s, z, ʃ/) have allophonic status. PCCC<sub>p</sub> 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. [slanə] or [çlanə] instead of /ʃlanə/, i.e. <snake>) and assimilations for /fl/ → [sl/ʃl] and /tʁ, dʁ/ → [kʁ gʁ] (e.g. [flafə] instead of /flafə/, 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.

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1  
2 In the cross-sectional data set, children were divided into two age groups, i.e. children aged  
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4 2;00-2;05 and 2;06-2;11. For each child, the number of CC(C)-words was counted and the number of  
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6 cluster productions according to the two PCCC categories calculated. This led to two overall PCCC  
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8 scores for each child. In addition, group PCCC mean scores for each cluster were computed (for the  
9  
10 young and old group separately). Moreover, a qualitative analysis of substitution and reduction  
11  
12 patterns was carried out. For the longitudinal study, PCCCs according to the two different categories  
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14 were calculated per child per month. In addition to qualitative and descriptive analyses, inferential  
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16 statistics were used to explore age effects (non-parametric correlations (Spearman) and group  
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18 comparisons (Mann-Whitney-U-tests)).  
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**Result**

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29 In order to answer how German-speaking children start producing clusters (research  
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31 question 1) the PCCC for the two different sub-categories for both young and old 2-year olds was  
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33 calculated (see Table II). Looking at the PCCC adult-like category (PCCCa), the younger 2-year olds  
34  
35 produced on average 24% of all consonant clusters correctly. The older 2-year olds showed a  
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37 percentage of over 55%. When accepting typical phonological processes (PCCCp), i.e. fronting and  
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39 backing of /f/, fronting of /k, g/ and assimilations, the younger ones showed a percentage of 40%  
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41 cluster production, the older ones' percentage increased to almost 74%.  
42  
43  
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45 However, standard deviations and the score range for both groups showed a large variability  
46  
47 in cluster production, some young children already showed a high number of correct clusters in  
48  
49 contrast to some older children whose PCCCs were still considerably low. If age-appropriate  
50  
51 phonological processes were accounted for, the majority of the older children were able to produce  
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53 consonant clusters. The number of children who did not produce any clusters as categorised was very  
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55 small (eight young children, two older children). Of those ten children eight children produced non-  
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57 adult like clusters and only two children produced no clusters at all.  
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**Running head:** Initial consonant clusters in German 2-year olds

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:  $r = .57$ ,  $p_{2\text{-tailed}} < 0.001$ ). 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-/f/-clusters had lower PCCCs, and /f/-clusters had the lowest PCCCs, including the three-element /f/-clusters.

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



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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 /f/ 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<sub>1</sub> for /gl/ and /kl/. In the older age group, there was a preference for C<sub>2</sub> 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<sub>1</sub>. In the older age group, the children still preferred C<sub>1</sub> but some of the C<sub>1</sub>C<sub>2</sub>-structures were also reduced to the second consonant (i.e. C<sub>2</sub>). The clusters /kv/ and /kn/ were most likely to be reduced to C<sub>2</sub> in both age-group.

For /f/-clusters, a general preference for reducing C<sub>1</sub> was observed. However, reduction patterns for /fl/ are less clear and resemble those with non-/f/+l/ clusters, showing reductions to C<sub>1</sub> or C<sub>2</sub> respectively. Additionally, the cluster /fʁ/ follows the pattern of the non-/f/+ʁ/ clusters, with a preference of C<sub>1</sub> in the younger or no preference in the older age-group.

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The three element clusters /ʃpʁ/ and /ʃtʁ/ were preferably reduced to C<sub>2</sub> or, less often, to C<sub>2</sub>C<sub>3</sub> 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<sub>2</sub>. The picture was less clear when only one element was reduced, any of the three options (C<sub>1</sub>C<sub>2</sub>, C<sub>2</sub> C<sub>3</sub>, or C<sub>1</sub>C<sub>3</sub>) 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-

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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.

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

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25 Data from cross-sectional studies and one longitudinal study were analysed to explore onset  
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27 cluster production in German-speaking 2-year olds. Results are discussed in relation to the research  
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29 questions.  
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32 The first research question aimed to investigate how clusters develop in German-speaking  
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34 children between the age of 2;00-2;11 when compared to adult-like productions but also when  
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36 developmental phonological processes are considered. The current study confirmed the expected trend  
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38 reported by McLeod et al. (2001a) as well as the results from studies on different languages (e.g.  
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40 Hebrew: Bloch, 2011; Portuguese: Freitas, 2003; Dutch: Jongstra, 2003; French: MacLeod et al.,  
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42 2011; English: McLeod et al., 2001a; German: Bartels, 2012) that 2-year olds are able to produce  
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44 consonant clusters and that cluster production correlates with age. When fronting/backing or  
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46 assimilations were accepted as phonologically correct productions (PCCCp), a procedure which has  
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48 not been applied so far in the literature, higher percentages of correct cluster production were found  
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50 for the category. This was specifically true for /f/-clusters, where the typical fronting or backing of the  
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52 singleton /f/ was observed within the cluster. These substantially higher PCCC scores indicate already  
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54 stable cluster productions in general. This underlines the importance to differentiate children's  
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56 performance and to account for typical phonological processes. It also shows that children can  
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**Running head:** Initial consonant clusters in German 2-year olds

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/, /ʃʒ/, 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

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2 directed speech. In addition, /f/-clusters comprising of /f/+stop (i.e. /ft/ and /fp/) which violate the  
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4 Sonority Sequencing Principle were acquired at the same rate as other /f/-clusters such as /fm/.

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6  
7 The assumption that markedness based on sonority distance impact on the acquisition of  
8  
9 clusters could be confirmed for the two clusters the older group acquired first (i.e. /gl/, /kl/). Based on  
10  
11 Hogg and McCully's (1987) sonority scale the distance between both consonants is four or five  
12  
13 respectively. However, the other clusters did not follow this principle. For example, in both age  
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15 groups /dʁ/ and /kn/ were acquired at the same time despite their diverging sonority difference (2 and  
16  
17 4 respectively). Hence, sonority principles do not fully explain the order of cluster acquisition in  
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19 German which is in line with data from other languages (for example Polish, see Yavaş & Marecka,  
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21 2014).

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24 The current study also addressed the question whether 2-element clusters are acquired  
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26 before 3-element clusters. The data revealed that 3-element clusters were acquired at the same rate as  
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28 2-element clusters which contradicts McLeod et al.'s (2001a) trend that 2-element clusters are  
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30 acquired prior to 3-element clusters and provides some evidence that phonotactic complexity may not  
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32 necessarily impact on cluster production. On the other hand, there are less 3-element clusters to be  
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34 acquired in German (i.e. /ʃpʁ/, /tʁ/) than in English (4) However, French includes five 3-element  
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36 clusters but similar to German findings on French showed no difference in the acquisition of /sku/ in  
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38 comparison to 2-element clusters (MacLeod et al., 2011). The early acquisition of the 3-element  
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40 clusters might be influenced by the high lexical frequency of words with /ʃpʁ/ and /tʁ/ in child  
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42 directed speech as suggested by data from Ota & Green (2013).

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49 Children who produce words that include initial clusters realise these in different ways.  
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51 Cluster reduction and substitution have been claimed to be the most common pattern (e.g. MacLeod et  
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53 al., 2011; McLeod et al., 2001a; Smit, 1993). Within these pattern clusters behave differently as to the  
54  
55 types of substitutions of the elements to be reduced. Research question three investigated the  
56  
57 realisation patterns in German-speaking children and whether any specific relationships between those  
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1  
2 patterns and correct production exist. Results from the current study indicated that cluster reduction  
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4 and cluster substitutions were found, which is in agreement with findings on English (Smit, 1993) and  
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6 French (MacLeod et al., 2011). However, additional patterns such as epenthesis, metathesis or  
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8 coalescence which were described by Chin & Dinnsen (1992) were not found. In very rare occasions a  
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10 cluster was deleted.  
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13 For an in-depth understanding of reduction patterns, which may be relevant for clinical  
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15 decision making, a qualitative analysis of the data was conducted. It revealed different reduction  
16  
17 patterns as a function of both age and type of cluster. In both age groups, clusters containing a plosive  
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19 or /f/ followed by /l/ were either reduced to C<sub>1</sub> or C<sub>2</sub>. This finding is not in line with results reported  
20  
21 for other languages where C<sub>1</sub> is generally described to be the remaining consonant (Spanish: Barlow,  
22  
23 2003; Portuguese: Freitas, 2003; Dutch: Jongstra, 2003; English: Smit, 1993). However, in Hebrew  
24  
25 there seems to be a preference for C<sub>2</sub> (Forkush, 1997 as cited in McLeod, 2013). Hence, for those  
26  
27 clusters cross-linguistic differences are observable and data do not clearly support the sonority  
28  
29 principle. A clearer picture arose for the C+/ɸ/-clusters, C<sub>1</sub> was preferred by the majority of children.  
30  
31 This is in accordance with the languages mentioned above (except Hebrew: Ben-David & Berman,  
32  
33 2007) and studies on French (Demuth & McCoullough, 2009; MacLeod & Findlay, personal  
34  
35 communication, December 2015). Generally, those results are in line with the sonority principle,  
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37 assuming that the less sonorous consonant is kept. For /f/-clusters findings showed a preference for C<sub>2</sub>  
38  
39 which supported data from other languages (see references above). However, similar to findings on  
40  
41 Dutch (Jongstra, 2003), a slight preference of C<sub>1</sub> over C<sub>2</sub> in /f/-clusters containing /l/ or /ɸ/ was found.  
42  
43  
44 For a theoretical discussion on these clusters, please see Yavaş, Fox-Boyer & Schaefer (2016).  
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49 German-speaking children showed only few substitutions of phonemes, as had been  
50  
51 expected. Fronting of /k g/ and /f/ have also been reported by Smit (1993) for English and by  
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53 MacLeod & Findlay (in preparation) for French. Assimilation of /dɸ, tɸ/ to /gɸ, kɸ/ are also described  
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55 as typical for French by MacLeod & Findlay (in preparation). For English however, a very common  
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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



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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

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1  
2 application of different PCCC proved to be useful, showing that when phonetic and phonological  
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4 processes are accounted for, children achieve a considerably higher PCCC, including /ʃ/-clusters.  
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6 Longitudinal data showed diverse patterns, confirming intra- and inter-individual variability.  
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8 However, by the end of the study all children showed a considerable increase of PCCC, which  
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10 supports the notion that at the age of three children should be able to produce clusters. Concerning  
11  
12 developmental sequences, it was observed that younger 2-year-olds produced more reductions than  
13  
14 simplifications. The older 2-year-olds produced more simplifications for the /ʃ/-clusters, due to the  
15  
16 fact that the phoneme /ʃ/ had not been acquired.  
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20 Although clusters are commonly not addressed in speech intervention for two year olds, the  
21  
22 knowledge about how children realise and acquire clusters at an early age provides a baseline on  
23  
24 which cluster realisations in older children with speech disorders can be evaluated. Children with  
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26 speech sound disorders might follow a developmental age-appropriate or delayed path, but they may  
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28 also show deviant realisation patterns. Different intervention approaches might be necessary (Fox-  
29  
30 Boyer & Neumann, 2016).  
31  
32

### 33 34 35 36 37 **Declaration of interest**

38  
39 The authors report no conflicts of interest. The authors alone are responsible for the content  
40  
41 and writing of the paper.  
42

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45  
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47  
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49  
50

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**Running head:** Initial consonant clusters in German 2-year olds

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/ɰ/	fr θr	fʁ	fʁ vʁ
Stop + nasal / fricative		kn kv	ps
<b>Possibly adjunct consonant cluster</b>			
/s/ ʃ/+ stop	sp st sk	ʃt ʃp	sp st sk
/s/ ʃ/+ nasal	sn sm	ʃn ʃm	
/s/ ʃ/+ /ɹ/ɰ/	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
<b>Either true cluster or rising diphthong</b>			
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			bɥɥ, dɥw, tɥw

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



**Running head:** Initial consonant clusters in German 2-year olds

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

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

Note. <sup>1</sup> Adult-like productions: including (de)voicing/phonetic variations;

<sup>2</sup> adult-like productions and not accounting for fronting of /k, g/, fronting or backing of /f/, or assimilations.



**Running head:** Initial consonant clusters in German 2-year olds

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 /j/

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

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

Running head: Initial consonant clusters in German 2-year olds

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 <sub>1</sub> or C <sub>2</sub> * % (n)				Substitutions to C1 or C2 % (n)	Children showing specific substitutions* % (n)	Substitutions excl. processes % **				
		to C <sub>1</sub>		to C <sub>2</sub>								
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
	bɣ	54 (21)	b/p	91 (19)			ɣ	0 (0)	3 (1)			
	gɣ	43 (15)	g/k	86 (12)	d/	14 (2)	ɣ	0 (0)	11 (4)	dɣ	50 (2)	6
	kɣ	69 (31)	k/g	31 (10)	t/	56 (18)	ɣ	3 (1)	9 (4)	dɣ/tɣ	75 (3)	2
	dɣ	44 (23)	d/t	64 (16)	g	20 (5)	ɣ	14 (1)	21 (11)	gɣ/kɣ	82 (9)	6
	tɣ	52 (28)	t/d	82 (23)	g	7 (2)	ɣ	4 (1)	14 (7)	kɣ	100 (7)	0
	fɣ	53 (20)	f/v	75 (15)			ɣ	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)			
	ɲl	44 (23)	s/ç	30 (7)			l	54 (9)	52 (27)	sl/çl	100 (27)	0
	ɲm	62 (31)	s/ç	6 (2)			m	77 (24)	30 (15)	sm/çm	93 (14)	2
	ɲn	47 (17)	s/ç	18 (3)			n	76 (13)	42 (15)	sn/çn	100 (15)	0
	fɣ	46 (15)	s/ç	41 (7)	d	29 (5)	ɣ	12 (2)	45 (15)	sɣ/çɣ	73 (11)	12
	fɣv	42 (15)	s/ç	7 (1)			f/v	77 (10)	53 (19)	sv/çv	84 (16)	8
fɣt	48 (23)	s/ç	24 (7)			t/d	72 (21)	48 (23)	s/ç, t/d	100 (23)	0	
fɣp	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

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

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

Target	% of children reducing CCC to C	% of children reducing a CCC to either C <sub>1</sub> , C <sub>2</sub> or C <sub>3</sub> *								% of children reducing a CCC to CC	% of children reducing a CCC to CC*						% of children substituting CCC**	C <sub>1</sub> C <sub>2</sub> C <sub>3</sub>		
		C <sub>1</sub>	%	C <sub>2</sub>	%	C <sub>2</sub>	%	C <sub>3</sub>	%		C <sub>1</sub> C <sub>2</sub>	%	C <sub>2</sub> C <sub>3</sub>	%	C <sub>1</sub> C <sub>3</sub>	%		C <sub>1</sub> C <sub>2</sub> C <sub>3</sub>	%	
2;00- 2;05	fpx	58	s/ç	4	p/b	70		ɸ	4	36	s/ç, p/b	0	p/b, ɸ	100	s/ç, ɸ	0	24	s/ç, p/b, ɸ	100	
	ftɸ	41	s/ç	8	t/d	54	k/g	15	ɸ	15	34	s/ç, t/d	36	t/d, (k)	36	s/ç, ɸ	27	16	s/ç, t/d, ɸ	75
2;06- 2;11	fpx	16	s/ç	0	p/b	75		ɸ	25	20	s/ç, p/b	30	p/b, ɸ	35	s/ç, ɸ	10	27	s/ç, p/b, ɸ	95	
	ftɸ	7	s/ç	0	t/d	60		ɸ	40	21	s/ç, t/d	19	t/d, (k)	38	s/ç, ɸ	44	29	s/ç, t/d, ɸ	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.

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Table VI: Mean percentage (SD) of non-/j/- and /j/-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-/j/ cluster	/j/-cluster	Non-/j/ cluster	/j/-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)

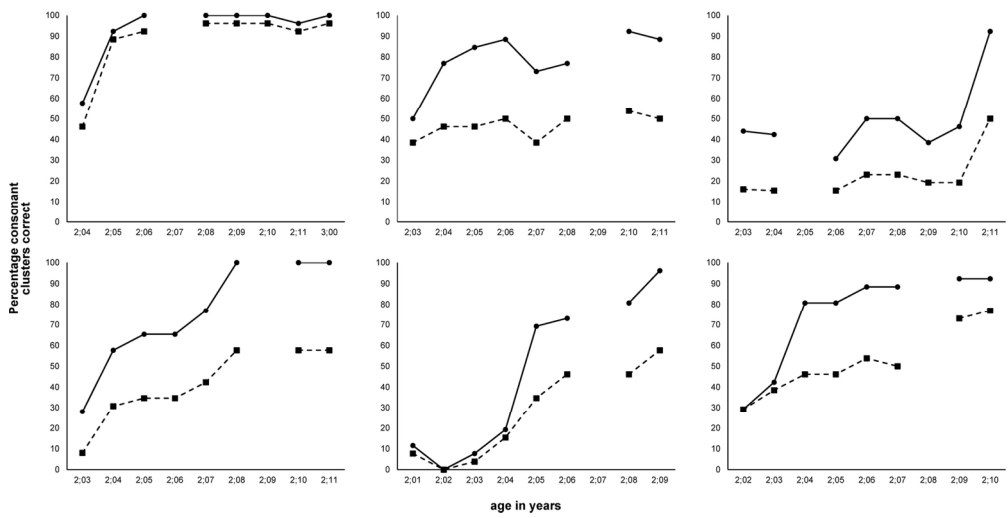
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**Running head:** Initial consonant clusters in German 2-year olds

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 (PCC Cp, see data analysis for a more details).

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144x73mm (300 x 300 DPI)

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Supplementary Materials: Table I: Overview of items from the PLAKSS

Item	Translation	Transcription
<u>Stuhl</u>	chair	ʃtul
<u>Spinne</u>	spider	ʃpɪnə
<u>Spagetti</u>	spaghetti	ʃpaɡɛti
<u>Schnecke</u>	snail	ʃnɛkə
<u>Zitrone</u>	lemon	ʃsitʁonə
<u>Brief</u>	letter	bʁɪf
<u>Zebra</u>	zebra	tʁɛbʁa
<b>Knöpfe</b>	buttons	knœpfə
<u>Flasche</u>	bottle	flaʃə
<b>Krokodil</b>	crocodile	kʁokodil
<u>grün</u>	green	ɡʁyn
<b>Blume</b>	flower	blumə
<b>Gespennst</b>	ghost	ɡɛʃpɛnst
<b>Drachen</b>	dragon	dʁaxə
<u>Strumpf</u>	sock	ʃtʁœmpf
<u>Glas</u>	glass	ɡlas
<u>Pflaster</u>	band aid	flastɛ
<b>Trecker</b>	tractor	tʁɛkɛ
<u>Schrank</u>	wardrobe	ʃʁɑŋk
<u>Brille</u>	glasses	bʁilə
<u>Gras</u>	grass	ɡʁas
<u>Schlange</u>	snake	ʃlaŋə
<u>Schornstein</u>	chimney	ʃœnʃtɛm
<u>Frosch</u>	frog	fʁɔʃ
<u>quak</u>	quack	kʁak
<u>Kleid</u>	dress	klɛt
<b>Schlüssel</b>	key	ʃlysɛl
<b>Schmetterling</b>	butterfly	ʃmɛtalɪŋ
<u>Spritze</u>	syringe	ʃpʁɪtsə

Note. All Items marked bold were part of the screening short form.



Supplementary Materials: Table II: Individual realisation patterns over time for each child (longitudinal data, ✓ = correct production)

Child 1																					
Age	bl	bɣ	dɣ	tɣ	fl	fɣ	gl	gɣ	kl	kn	kɣ	kv	ʃl	ʃm	ʃn	ʃp	ʃɣ	ʃt	ʃv	ʃpɣ	ʃtɣ
2;04	✓	✓	✓	✓	✓	✓	✓	✓	sl	sn	✓	v	✓	✓	sn	✓	✓	st	✓	✓	✓
2;05	✓	✓	✓	✓	✓	✓	✓	✓	✓	sn	fɣ	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2;07	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	sm	✓	✓	✓	✓	✓	✓	✓
2;08	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2;09	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2;10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2;11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	v	✓	✓	✓	✓	✓	✓	✓	✓	✓
3;00	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Child 2																					
Age	bl	bɣ	dɣ	tɣ	fl	fɣ	gl	gɣ	kl	kn	kɣ	kv	ʃl	ʃm	ʃn	ʃp	ʃɣ	ʃt	ʃv	ʃpɣ	ʃtɣ
2;03	✓	✓	kɣ	kɣ	✓	ɣ	✓	✓	✓	n	✓	b	l	m	sn	sb	h	d	sv	pɣ	kɣ
2;04	✓	✓	kɣ	kɣ	✓	✓	✓	✓	✓	✓	✓	b	sl	çm	sn	çb	tçɣ	sd	v	bɣ	ɣ
2;05	✓	✓	gɣ	kɣ	✓	✓	✓	✓	✓	✓	✓	b	çl	çm	sn	sb	çɣ	sd	v	spɣ	çt
2;06	✓	✓	kɣ	kɣ	✓	✓	✓	✓	✓	✓	✓	✓	sl	sm	tçn	sb	sɣ	sd	çv	sɣ	çdɣ
2;07	✓	✓	gɣ	kɣ	çl	✓	✓	✓	✓	✓	g	✓	çl	çm	çn	çb	sɣ	sd	tv	çb	çdɣ
2;08	✓	✓	kɣ	kɣ	✓	✓	✓	✓	✓	✓	✓	✓	sl	sm	çn	sb	kɣ	d	çv	çɣ	çgɣ
2;10	✓	✓	kɣ	✓	✓	✓	✓	✓	✓	✓	✓	✓	sl	çm	çn	çb	sɣ	ʃd	çv	çbɣ	sg
2;11	✓	✓	kɣ	kɣ	✓	✓	✓	✓	✓	✓	✓	✓	çl	çm	sn	çb	çɣ	ʃd	çv	çbɣ	sgɣ

## Child 3

Age	bl	bɣ	dɣ	tɣ	fl	fɣ	gl	gɣ	kl	kn	kɣ	kv	ɟl	ɟm	ɟn	ɟp	ɟɣ	ɟt	ɟv	ɟpɣ	ɟtɣ
2;03	✓	b	d	t	✓	f	l	g	✓	n	k	u	sl	sm	sn	sp	s	t	sv	p	
2;04	✓	b	d	t	sl	f	✓	g	✓	n	k	v	sl	m	sn	sp	sɣ	t	sv	p	t
2;06	✓	b	d	t	l	f	✓	g	✓	n	k	v	sl	m	sn	p	s	t	sv	p	t
2;07	✓	b	d	✓	l	f	✓	g	✓	n	✓	v	sl	sm	sn	sp	s	st	f	b	st
2;08	✓	b	d	✓	L	f	✓	g	✓	n	k	✓	l	sm	sn	sp	s	st	f	sp	stɣ
2;09	✓	b	d	✓	L	f	✓	g	✓	✓	k	v	sl	m	sn	b	s	st	f	b	sd
2;10	✓	b	d	t	sl	f	✓	g	✓	✓	k	v	sl	sm	sn	sp	s	st	v	b	d
2;11	✓	✓	✓	✓	sl	✓	✓	✓	✓	✓	✓	✓	sl	sm	sn	sp	sɣ	st	sv	spɣ	stɣ

## Child 4

Age	bl	bɣ	dɣ	tɣ	fl	fɣ	gl	gɣ	kl	kn	kɣ	kv	ɟl	ɟm	ɟn	ɟp	ɟɣ	ɟt	ɟv	ɟpɣ	ɟtɣ
2;03	l	b	g	g	w	f	l	g	✓		k	f	l	m	ɟn	ɟp	ɟ	sd	tv	p	d
2;04	✓	✓	✓	✓	✓	f	✓	g	k	pn	d	tf	ɟl	m	ɟn	b	ɟ	ɟd	ɟv	p	ɟd
2;05	✓	✓	✓	t	✓	f	tl	✓	✓	✓	t	fv	ɟl	ɟm	ɟn	ɟb	ɟj	ɟd	ɟv	b	ɟd
2;06	✓	✓	ɣ	ɣ	✓	ɣ	✓	ɣ	✓	✓	✓	kɣ	ɟl	ɟm	ɟn	ɟb	tɣ	sd	ɟv	ɟb	del
2;07	✓	✓	✓	ɣ	✓	✓	✓	ɣ	✓	✓	✓	ɣ	ɟl	ɟm	ɟn	ɟb	ɟɣ	ɟd	ɟ	ɟbɣ	ɟɣ
2;08	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	sl	ɟm	ɟn	sb	sɣ	sd	sv	ɟbɣ	sdɣ
2;10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	ɟl	ɟm	ɟn	ɟb	ɟɣ	ɟd	sv	ɟbɣ	sdɣ
2;11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	sl	sm	sn	sb	sɣ	ɟd	sv	sbɣ	sdɣ

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Child 5

Age	bl	bɣ	dɣ	tɣ	fl	fɣ	gl	gɣ	kl	kn	kɣ	kv	ɟl	ɟm	ɟn	ɟp	ɟɣ	ɟt	ɟv	ɟpɣ	ɟtɣ
2;01	✓	b	g	d	h	f	g	g	d	m	d	v	çl	m	n	b	d	d	v	b	d
2;02	b	b	g	d	v	p	g	g	k	n	t	b	l	m	n	b	d	p	v	p	g
2;03	b	b	g	t	b	b	g	g	g	k	t	b	l	m	n	b	ç	çd	b	b	d
2;04	l	fɣ	çɣ	t	f	✓	✓	✓	l	n	ɣ	v	l	m	n	b	ɣ	çt	sv	ɣ	tɣ
2;05	✓	✓	✓	✓	f	bɣ	l	✓	✓	fn	✓	✓	l	m	çn	çb	çɣ	çd	çv	çbɣ	çdɣ
2;06	✓	✓	✓	✓	✓	✓	✓	✓+tɣ	✓	✓	✓	v	l	çm	sn	çb	çɣ	d	çv	pɣ	çɣ
2;08	✓	✓	✓	✓	✓	✓	tl	✓	✓	n	✓	✓	çl	çm	çn	çb	çɣ	çd	f	çpɣ	çdɣ
2;09	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	çl	çm	çn	çb	çɣ	çt	tv	çpɣ	çtɣ

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Child 6

Age	bl	bɣ	dɣ	tɣ	fl	fɣ	gl	gɣ	kl	kn	kɣ	kv	ɟl	ɟm	ɟn	ɟp	ɟɣ	ɟt	ɟv	ɟpɣ	ɟtɣ
2;02	l	b	✓	✓	ɣ	dɣ	✓	✓	✓	pf	∅	v	l, v	∅	n	b	pɣ	d	v	kɣ	dɣ
2;03	✓	✓	✓	✓	✓	ɣ	✓	✓	✓	n	d	f	del	m	n	b	tɣ	d	çtɣ	pɣ	çtɣ
2;04	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	d	v	çl	m	çn	çb	çɣ	çd	çv	çbɣ	çɣ
2;05	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	d	b	çl	çm	✓	çb	çɣ	çd	çv	çbɣ	çɣ
2;06	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	d	b	✓	çm	✓	çb	çɣ	çd	çv	çbɣ	çdɣ
2;07	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	d	b	çl	çm	çn	çb	ç	çd	çv	çbɣ	çdɣ
2;09	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	d	✓	✓	✓	✓	sb	çɣ	çd	✓	çpɣ	çɣ
2;10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	d	✓	✓	çm	✓	çb	✓	çd	✓	çb	✓

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Note. ∅ = item not named by the child.