

Gradient phonotactics and frequency: A study of German initial clusters

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This paper investigates gradient markedness of word-initial consonant clusters in present-day Standard German. Markedness is determined on the basis of a phonotactic principle referred to as Net Auditory Distance. This study expands on previous analyses involving the principle by investigating which well-formedness indices implemented in the principle account best for corpus-based frequencies of consonant clusters. These indices encompass auditory distances pertaining to the manner of articulation, place of articulation and the sonorant/obstruent distinction. Linear regression modelling involving several types of distances as independent variables has revealed a positive correlation between type frequency and only one of the indices. More specifically, type frequency increases with an increase in the sonority distance between two adjacent consonants within a cluster. This finding suggests that a well-defined distribution of sonority distances constitutes a relevant phonotactic primitive and motivates the core structure of clusters available in German.

KEYWORDS: phonotactics, consonant clusters, distance, frequency, German.

1. Introduction

The phonotactic grammar of a language specifies possible combinations of segments. Phonological theory has been confronted with a challenge of accounting for strings of consonants, which are considered to be universally marked (Greenberg 1978). The distributional patterns of consonant clusters were shown to depend on prosodic cues (e.g. Shatzman & McQueen 2006; Warker & Dell 2006) as well as on frequency and markedness (e.g. Jusczyk *et al.* 1994; Stites *et al.* 2004; Jarosz 2007; Van de Vijver & Baer-Henney 2012; Dziubalska-Kořaczyk 2014, 2015). This line of research has also been pursued in relation to German. Phonotactic constraints in German have been discussed from the perspective of theoretical approaches (Vennemann 1982, 1988; Hall 1992; Wiese 2000), descriptive statistics (Orzechowska & Wiese 2011, 2015; Wiese & Orzechowska *in review*), morphological complexity (Dressler & Dziubalska-Kořaczyk 2006; Calderone *et al.* 2014) and using different areas of external evidence such as language acquisition (Grijzenhout

& Joppen-Hellwig 2002; Grijzenhout & Penke 2005; Selch *et al.* 2009; Schaefer & Fox-Boyer 2017; Yavaş *et al.* 2018), and online processing (Domahs *et al.* 2009; Steinberg *et al.* 2011; Korecky-Kröll *et al.* 2014; Celata *et al.* 2015; Ulbrich *et al.* 2016; Ulbrich & Wiese 2018).

In this paper, we focus on the relationship between frequency and phonotactic markedness with a view to answering the following questions:

Is there a relationship between the structure of clusters, and their type and token frequencies?

If yes, which phonetic/phonological properties constitute the best predictors of frequency?

Which properties should be considered in the classification and evaluation of clusters?

The selection of the language and the theoretical approach provide an excellent testing ground for the questions posed. First, the analysis is based on word-initial consonant sequences in present-day Standard German, which is considered to be phonotactically complex (Maddieson 2013). The language features strings composed of up to three consonants word-initially (e.g. /ʃtr/ in *Strand* ‘beach’), and four word-finally (e.g. /rpst/ in *Herbst* ‘autumn’). Second, the measure of phonotactic preferability used for the description and classification of clusters in this paper goes beyond principles that have been traditionally used in research on phonotactics. Consonant clusters in German have been studied mainly with respect to the manner of articulation features, or sonority (e.g. Wiese 1988; Hall 1992). The present contribution extends the previous analyses by investigating the phonotactic preferability in terms of a wide range of distances incorporated into the Net Auditory Distance principle (Dziubalska-Kořaczyk 2009, 2014, 2019).

The principle determines the preferability status of clusters on the basis of numerous indices representing auditory distances that pertain to the place of articulation and the laryngeal contrast, beyond sonority-related distances. Auditory distances are assumed to be a direct consequence of articulatory gestures. Therefore, articulatory features are used to calculate the resulting auditory distances (see Table 1). Such an approach provides a more detailed account of the phonological structure of clusters than the sonority principle (see Section 2.1), and makes the results of the analysis comparable to approaches that employ a large set of cluster-defining parameters (e.g. Orzechowska & Wiese 2015). Moreover, the present paper offers an extension of cross-linguistic analyses involving Net Auditory Distance (e.g. Dziubalska-Kořaczyk 2014;

Baroni 2014b; Zydorowicz *et al.* 2016) by decomposing well-formedness conditions employed in the principle into constituent distance indices, and by identifying the indices that contribute the most to different frequency measures. It is expected that some distance indices employed in the phonotactic principle constitute better predictors of type and token frequencies than others.¹

This paper is a response to several themes pursued in phonological research. First, the results contribute to the ongoing discussion on the mental lexicon, usage-based phonology and cognitive phonology (e.g. Bybee 2001; Langacker 1988; Van der Hulst 2003; Kristiansen 2006 including numerous references therein). Some approaches posit that linguistic structures are shaped by language use. As to German, recent work by Wiese & Orzechowska (*in review*) suggests that preferred phonetic/phonological structures and their usage frequency constitute two distinct domains for which distributions are largely independent, and which do not have to coincide. We build on this analysis by studying the same corpus-based dataset and including a different set of variables.

Additionally, the present study contributes to the discussion on how the universal primitive of markedness (see Batistella 1990; De Lacy 2006) should be defined. Since the paper investigates the role of phonetic distances in phonotactic well-formedness, it furthers the work of, among others, Clements (1990) and Parker (2012), who employed the concept of sonority distance and sonority differential in determining cluster naturalness. Moreover, by including place, manner and laryngeal distances in the analysis, this study draws on the concept of the relative weight of phonological features proposed in Orzechowska (2016, 2019). As demonstrated in Orzechowska (2019), while specific subsets of place, manner and voice features motivate the core structure of clusters available in a language, other sets of features are critical for production facilitating effortless articulation, and perception facilitating neuro-cognitive processing. The present study pursues a related question by asking which phonetic distances contribute the most to cluster well-formedness.

2. Phonotactic principles

2.1. Sonority as an articulatory measure

The Sonority Sequencing Generalization (henceforth **SSG**, Selkirk 1984), as the most recognized measure of phonotactic markedness, regulates the linear arrangement of segments in syllables. This linear ordering is based on the relative loudness (sonority) of sounds, which corresponds to the degree of articulatory aperture (Ladefoged 2006) (see

also acoustic accounts in, e.g., Ohala 1992; Parker 2002, 2012). Vowels, characterized by a relatively open articulation, are the most sonorous sounds, while obstruents, which obstruct the airflow, are the least sonorous sounds. The generalization states that a well-formed syllable should display a sonority rise from the most marginal consonant (C) towards a vowel (V) as in CCVCC words *Trend* /trent/ ‘trend’, *schlank* /ʃlanʁk/ ‘slim’, *Prost* /prɔst/ ‘cheers’. The monosyllables follow the SSG-based ordering according to the sonority scale proposed by Wiese (1988) and Hall (1992).

- (1) Sonority-based syllable structure in German

obstruents < nasals < /l/ < /r/ < **vowels** > /r/ > /l/ > nasals > obstruents

onset

nucleus

coda

The sonority slope is not the only principle used in determining the markedness status of clusters. Another way of evaluating phonotactic preferability involves calculating sonority distances. The concept of distance has been used in various ways in relation to sonority. The most oft-quoted Sonority Dispersion Principle (Clements 1990) states that preferred CCV and VCC demisyllables should be characterized by a sharp rise in sonority from the left-most consonant towards a vowel and a minimum sonority fall from the vowel rightwards, respectively, based on the following scale of decreasing sonority: vowels > glides > liquids > nasals > obstruents. Thus, the most natural C1C2V is represented by an obstruent + liquid + vowel combination as it involves a steady and gradual rise in sonority. Such a sequence occupies the whole sonority spectrum from an obstruent in C1 to a vowel. Also, a liquid in C2 exhibits a two-step distance towards the margins of the sequence, ensuring an optimal distribution of C1C2 and C2V distances. In turn, liquid + glide + vowel represents the least natural sequence due to a small rise in sonority. The notion of distance is also implemented in the auditory model of preferability employed in the present paper.

2.2. Net Auditory Distance²

Net Auditory Distance (henceforth **NAD**, Dziubalska-Kołaczyk 2009, 2014, 2019) is an auditory principle of phonotactic preferability. It stems from Beats-and-Binding Phonology (Dziubalska-Kołaczyk 2002), which is a syllable-less theory of phonology implemented in the framework of Natural Linguistics (see Donegan 1985, 2002; Donegan & Stampe 1979; Dressler 1985, 1996; Stampe 1979). The basic phonological components constitute beats (preferably associated with vowels)

and non-beats (associated with consonants). The degree of cohesion between beats and non-beats is determined by bindings. The way in which sequences of consonants group around vowels reflects phonotactic preferences defined in terms of auditory distances between pairs of segments. The strength of a binding is expressed by the size of perceptual contrast between sounds: the larger the contrast, the more perceptible the sequences and the more preferred the cluster. Thus, the syllable structure in Beats-and-Binding Phonology is derived from the relationship between pairs of segments (consonants and vowels) without the necessity of evoking traditional concepts of onsets, rhymes, and codas as phonotactic primitives.

2.2.1. Auditory distances and phonotactics

NAD is grounded in contrast in line with the psychological principle of figure and ground. This principle regulates a preference for binary contrast whereby figures tend to be foregrounded, and grounds tend to be backgrounded (Dressler 2009). Similarly, in phonotactics, segments in a preferred sequence should be sufficiently different from each other in order to be clearly perceived. Such a differentiation is guaranteed by a combination of a quieter consonant and a louder vowel. This combination is best represented by a consonant + vowel sequence (CV), which is the most basic syllable template across the languages of the world (Greenberg 1978; Maddieson 2013). Apart from the CV preference, there is a body of phonetic evidence supporting the perceptual primacy of the CV transition. As observed by Maddieson (1999), “differentiation of sound in all (spoken) languages consists of an alternation between louder and quieter levels of sound (...), [a] fairly regular wave-like alternation of amplitude peaks and valleys” (1999: 2525). Similarly, Ohala (1990) notes that “the most salient acoustic modulations in a syllable occur near the CV interface” (1990: 265). That is, on the perceptual level, auditory cues in CV are much more robust and richer in place cues than in VC, resulting in the facilitative role of CV transition for the clarity of perception. The CV structure also supports ease of articulation: speakers attempt more precise articulations at CV interface compared to VC interface (Ohala & Kawasaki 1984). Phonologically, the relevance of contrast is captured in Donegan & Stampe (1979, 2009) who argue that fortitions enhance clarity of perception. These premises constitute the basis for perceptual distances and their optimal distribution in a string of segments (both CV and CC), as implemented in the NAD principle.

2.2.2. Measuring NAD in German

NAD is an extended version of the Optimal Sonority Distance Principle (Dziubalska-Kořaczyk 2001) which predicts an optimal distribution of manner distances in a successful sequence of two (CC) and three (CCC) consonants. NAD accounts for a wider array of criteria in cluster description and performs calculations over three types of distances (henceforth **dist**): the manner of articulation (henceforth **MOA**), the place of articulation (henceforth **POA**), and the sonorant-obstruent distinction (henceforth **S/O**). Table 1 presents the general classification of German consonants based on seminal phonological descriptions (e.g. Meinhold & Stock 1980; Kohler 1990; Hall 1992; Wiese 2000) and the Duden phonetic dictionary (2009). The included segments correspond to the underlying (phonemic) inventory of German, and do not account for allophones. The distances are computed for pairs of consonants (C1C2 in CC; C1C2 and C2C3 in CCC) and for the CV string (C2V in CC; C3V in CCC).

OBSTRUENT			SONORANT				VOWEL		
STOP	FRICATIVE		NASAL	LIQUID		GLIDE			
	AFFRICATE			LATERAL	RHOTIC				
5.0	4.5	4.0	3.0	2.5	2.0	1.0			
p b			m				1.0	BILABIAL	LABIAL
	pf	f v					1.5	LABIO-DENTAL	
t d	ts	s z	n	l			2.0	ALVEOLAR	CORONAL
		ʃ ʒ					2.5	POST-ALVEOLAR	
		ç j				j	3.0	PALATAL	DORSAL
k g		x	ŋ				3.3	VELAR	
		ʁ			r		3.6	UVULAR	
							4.0		RADICAL
		h					5.0	GLOTTAL	GLOTTAL

Table 1. MOA and POA distances in German.

The distance of 1 (dist = 1) holds between consecutive broad phonological features, while tens indicate the intervening places and manners of articulation (for a detailed exposition of the model and the motivation for the overall classification see Dziubalska-Kořaczyk 2019). The

MOA classes in Table 1 correspond to sonority classes, with their basis in acoustic energy. The numerical values posited for the POA scale are more arbitrary. In the absence of acoustic phonetic measures related to such distances, the place categories are selected on the basis of their potential relevance. Five POA distances (dist=1-5) are thus connected with their anatomical location in the vocal tract, and are drawn from the universal classification of segments in Ladefoged (2006). As to laryngeal features, the S/O distinction is included as a replacement for the feature ‘voice’. According to Kehrein & Golston (2004), laryngeal features are non-redundant only within subclasses of sonorants and obstruents. Therefore, the S/O distinction provides a more detailed phonetic description compared to the [\pm voice] feature. The S/O distance is expressed by values 0 and 1 depending on whether adjacent segments are either obstruents or sonorants, or whether they belong to different classes. Dist=0 specifies S + S and O + O sequences, while dist=1 holds between segments which belong to two different classes, namely S + O and O + S.

2.2.3. Calculating NAD

The computation of distances follows the formula: $NAD = |MOA| + |POA| + |S/O|$, which is incorporated into well-formedness conditions for clusters of different size (CC, CCC) and found in different word positions (initial, medial, final). In (2), we list hypotheses for preferred initial CCs and CCCs. The hypotheses reflect the phonetic preferences outlined in Section 2.2.1. Since the CV binding is prosodically the strongest, there must exist a force which ensures the preservation of strings of consonants around vowels. This force is represented by the principle of perceptual contrast and is measured by means of distances. In a successful cluster, the C-C distance is expected to be larger than the C-V interface, leading to larger contrast and enhanced perceptual clarity.

Let us illustrate the procedure of calculating distances on the example of initial CCs and CCCs.

- (2) Well-formedness conditions for clusters of length 2 and 3
- a. C1C2: $NAD(C1,C2) \geq NAD(C2,V)$
 - b. C1C2C3: $NAD(C1,C2) < NAD(C2,C3) \geq NAD(C3,V)$, where:
 $NAD(C1C2) = |(MOA1 - MOA2)| + |(POA1 - POA2)| + |S/O|$, and
 $NAD(C2C3) = |(MOA2 - MOA3)| + |(POA2 - POA3)| + |S/O|$, and
 $NAD(C2V) = |(MOA2 - MOAV)| + |S/O|$

The condition for a preferred C1C2 reads: the distance between two consonants should be larger than or equal to the distance between a consonant and a vowel. A universally preferred C1C2C3 should exhibit

the largest distance in the medial pair of consonants. Table 2 details the calculations for selected two- and three-member clusters. The column referred to as ‘NAD product’ specifies the final distance value for a cluster; it is an index expressing the degree of cluster preferability. In initial C1C2s, NAD product is calculated by means of subtraction: $\text{NAD}(\text{C1-C2}) - \text{NAD}(\text{C1-V})$. In initial CCCs, the following formula is used: $(\text{NAD}(\text{C2-C3}) - \text{NAD}(\text{C1-C2})) + (\text{NAD}(\text{C2-C3}) - \text{NAD}(\text{C3-V})) / 2$. A positive numerical value specifies a cluster which follows the well-formedness conditions (= preferred cluster). A negative value is an indicator of a violated condition (= dispreferred cluster, marked with an asterisk).

CLUSTER	C1-C2 MOA + POA + S/O	C2-C3 MOA + POA + S/O	C2-V / C3-V MOA + S/O	CONDITION	NAD PRODUCT
/bj/	$ 5-1 + 1-3 + 1 = 7$	—	$ 1-0 + 0 = 1$	$7 \geq 1$	6
/ft/	$ 4-5 + 2.5-2 + 0 = 1.5$	—	$ 5-0 + 1 = 6$	$*1.5 \geq 6$	-4.5
/tsv/	$ 4.5-4 + 2-1.5 + 0 = 1$	—	$ 4-0 + 1 = 5$	$*1 \geq 5$	-4
/jpl/	$ 4-5 + 2.5-1 + 0 = 2.5$	$ 5-2.5 + 1-2 + 1 = 4.5$	$ 2.5-0 + 0 = 2.5$	$2.5 < 4.5 \geq 2.5$	2
/jtr/	$ 4-5 + 2.5-2 + 0 = 1.5$	$ 5-2 + 2-3.6 + 1 = 5.6$	$ 2-0 + 0 = 2$	$1.5 < 5.6 \geq 2$	3.85
/skl/	$ 4-5 + 2-3.3 + 0 = 2.3$	$ 5-2.5 + 3.3-2 + 1 = 4.8$	$ 2.5-0 + 0 = 2.5$	$2.3 < 4.8 \geq 2.5$	2.4

Table 2. The classification of selected initial clusters in German.

Based on NAD product values, the following preferability hierarchy can be established: /bj/ > /jtr/ > /skl/ > /jpl/ > /tsv/ > /ft/, where ‘>’ indicates a decrease in distance, and the ensuring decrease in preferability. Note that this gradient scale varies depending on the classification of some consonants.

2.2.4. Phonetic variants: consequences for NAD

The German rhotic has numerous realizations (Hall 1993; Schiller 1998; Wiese 2001, 2003, 2011) ranging from an alveolar trill, a uvular trill or fricative to a uvular approximant. Interestingly, in the history of German, these and other allophonic variants co-existed in the same period of time. A dialectal study of Göschel (1971) demonstrated that in the 1930s the prevocalic rhotic was realized as a tap, trill, fricative or an approximant articulated in either region: alveolar, retroflex, velar or uvu-

lar. The variation is still observable across German varieties and dialects. For instance, in Austrian and Swiss German, Ulbrich & Ulbrich (2007) reported 12 different phonetic variants of /r/, next to its zero realization. In spite of the differences in the place and manner of articulation, the class of rhotics is phonotactically stable (Wiese 2001, 2003). First, irrespective of its classification, the rhotic occupies the same position in a consonant cluster suggesting that its sonority value remains unchanged. The /r/-type segment appears in onset and coda clusters closer to a vowel rather than on syllable margins. Also note that the sonority scale in (1) orders the rhotic between the lateral and vowels. Second, the rhotic combines with any stop in initial position, which does not hold true for other sonorants. For instance, while phonotactic constraints in German prohibit onsets composed of plosives followed by homorganic nasals and /l/ as in */pm bm bn tl tn dl dm dn/, /r/ combines with all the plosives.

These observations legitimize the use of virtually any variant for the purpose of the present analysis. However, the overall NAD value will change depending on the classification. For instance, a /t/ + rhotic cluster is dispreferred when the rhotic is a uvular fricative /ʁ/ (NAD product = -2.4), and preferred when the consonant is a uvular liquid /R/ (NAD product = 3.6) or an alveolar trill /r/ (NAD product = 1.0). The question is thus which variant to employ in the present analysis. Adopting a phonetic perspective would make a trill possibly the most adequate variant. In terms of universal preferability, a voiced alveolar trill /r/ is the prototypical unmarked r-sound due to its coronal, and hence unmarked place of articulation. The cross-linguistic primacy of this pronunciation variant was shown in the UPSID database (Maddieson 1984). In German, a sonorant (trill) realization of the rhotic was argued for in Ulbrich (1972), Hall (1992) and Barry (1997), while an obstruent (fricative) realization was posited in Kohler (1990) and Schiller (1998). For the time being, we disregard the existing variation, and leave it as a possible area of investigation for our future work. For the purpose of the present analysis, we use the uvular liquid (/R/) as a target.

Another problem area is related to the classification of the voiced palatal consonant. The descriptions of German by Kohler (1990) and Maddieson (1984) define the segment as an approximant /j/, while Wiese (2000) and the Duden (1990) phonetic dictionary classify the consonant as a fricative /j/. In terms of NAD, the discrepancies in the classification lead to substantially different results. Clusters containing a glide are preferred and their NAD product values place them among the most preferred CCs (/bj/ = 6, /fj/ = 4.5, /tj/ = 5, where /bj/ displays the highest value in the dataset), while clusters containing a fricative are moderately dispreferred (/bj/ = -2, /fj/ = -3.5, /tj/ = -3). In line with

the IPA classification by Kohler (1990), we follow the first approach and analyse /j/ as a semi-vowel.

2.2.5. NAD vs sonority-based approaches

Although phonotactics of German has been extensively studied in the subject literature (see references in Section 1), the NAD principle offers a new approach to the analysis of cluster structure, and complements the existing accounts. On the one hand, the method employs phonetic distances, which makes it largely comparable to principles regulating the distribution of sonority distances in a sequence (e.g. Clements 1990; Selkirk 1984; Parker 2012). Such principles mainly account for the manner of articulation features, which are in NAD represented by individual MOA distances between two consonants (e.g. |(MOA1 - MOA2)|) and between a consonant and a vowel (e.g. |(MOA2 - MOAV)|). Given more detailed sonority scales, sonority distances can also be computed over obstruent classes varying in terms of voicing, where voiceless plosives, fricatives and affricates are less sonorous compared to their voiced counterparts. In NAD, this type of distance is expressed by the laryngeal contrast (i.e. |S/O|).

On the other hand, NAD expands on the previous findings in several ways. First, it includes the place of articulation distances, indirectly addressing phonological principles which ban adjacent homorganic segments from the underlying representation (e.g. McCarthy 1988; Yip 1988). Second, the principle can be applied to a wider array of cluster types as it applies to the word domain (for similar arguments see Steriade 1999) rather than to the syllable domain. Moreover, the well-formedness conditions are specific to clusters in different positions in a word, i.e. initial, medial and final. In consequence, NAD can be used in the study of morphologically-motivated clusters (Dressler & Dziubalska-Kołodziejczyk 2006), which are generally excluded from the study of syllable onsets and codas.³

Another way in which NAD substantially diverges from sonority-based principles lies in the classification of clusters starting with strident fricatives. /s/ + stop (+ approximant) clusters pose challenges for phonological theory. When analysed as branching onsets, sC sequences are sonority-violating, which is problematic given their acoustic salience and high frequency in phonotactically rich languages. As a result, the special status of /s/C(C) was shown to mirror that of word-medial clusters. Kaye (1992) argued that /s/ + stop represents a structure composed of a rhymal complement hosting /s/ and an onset hosting a voiceless plosive (rather than a branching onset). Similarly, Goad (2012,

2016) provided typological and L2 acquisition evidence in favour of the coda + onset analysis of sC, which ensures a well-formed sonority profile of syllable constituents. In German, onsets are mainly composed of an obstruent followed by a non-homorganic sonorant such as /kn pl fr/ in *Knie* 'knee', *Platz* 'place', *Freude* 'happiness', see also Table 3. The only segments which can occur before stops or stop + sonorant sequences constitute /s/⁴ and /ʃ/, e.g. /st ʃt ʃpʁ ʃpl/ in *Star* (from English *Star*), *Stadt* 'city', *Sprecher* 'speaker' and *Spleiß* 'splice'. The fricatives are also the only consonants admitted before /m/, e.g. /sm ʃm/ in *Smaragd* 'emerald' and *Schmied* 'smith'. Therefore, arguments were raised in favour of appending the strident fricatives to a separate slot outside of the syllable (Vennemann 1982; Wiese 1988; Hall 1992; Grijzenhout & Joppen-Hellwig 1999; Goad & Rose 2004).

In contrast to syllable-based approaches, NAD is easily applicable to word-initial clusters that start with the fricatives. The principle classifies /s ʃ/-initial CCs as dispreferred and /s ʃ/-initial CCCs as preferred. This difference is attributed to the well-formedness conditions in (2) regulating the distribution of distances in pairs of segments. In C1C2V, the distance between a pair of consonants should be larger compared to the distance between a consonant and a vowel. This condition is always violated in /s ʃ/ + stop sequences as the C2V juncture, represented by a combination of a voiceless plosive and a vowel, is acoustically and perceptually most salient. In turn, the largest distance in three-member clusters should be found in the medial pair. This distributional preference holds true for all /s/CC and /ʃ/CC sequences as the C2C3 juncture is most salient: C2 and C3 slots are occupied by voiceless plosives and sonorants, respectively. These predictions stipulate an unmarked status of at least some types of fricative-initial clusters, which partly goes in line with formal approaches arguing for the universality of the fricative + plosive ordering in onsets (Morelli 1999).

3. Study

3.1. Data

The data (both clusters and frequencies) analysed in this study were drawn from Orzechowska & Wiese (2015), who used phonological descriptions, dictionaries and a text corpus (e.g. Meinhold & Stock 1980; Wiese 2000, Duden 2009, *Leipziger Wortschatz Portal*) to extract a representative list of clusters. The inventory comprises 54 word-initial clusters (46 CC, 8 CCC), including sequences found in some rare words as well as well-adapted loans and proper nouns such as /ʃk/ in *Schkopau*, /

bj/ in *Björn*, /skv/ in *Squash*. Some clusters were excluded due to their notably foreign status or dubious pronunciation, e.g. /dnj/ in *Dnjepr*, /Rj/ in *Rjasanow* and /bd/ in *bdellium*. For cluster types that occur in free variation such as [kv kf ku] (Kurka 1965), the basic /kv/ variant was used. The list of clusters (in alphabetical order) analysed in the study is presented in Table 3.

CLUSTER SIZE	CLUSTER TYPE
CC	bj bl br dr fj fl fr gl gm gn gr kl km kn ks kr kv pfl pfr pl pn ps pr sf sk sl sm sn sp sr st sts sv ſk ſl ſm ſn ſp ſr ſt ſv tj tr tv tsv vr
CCC	skl skr skv spl str ſpl ſpr ſtr

Table 3. Cluster types.

Type and token frequencies of clusters were compiled from the corpus of newspaper texts of present-day Standard German *Leipziger Wortschatz-Portal*. The corpus contains 172 million word tokens representing 1.65 million word types. In this and further sections of the paper, the term type frequency is used to refer to the cumulative frequency of words which contain a particular initial cluster, while token frequency summarizes the total number of such words' repetitions in the corpus. For instance, the corpus features 429 word types starting with /kl/, such as *klein* 'small', *kleben* 'to glue' and *Kleid* 'dress', whose total frequency of occurrence equals 463 396. Therefore, type and token frequencies of word-initial /kl/ amount to 429 and 463 396, respectively. A complete list of clusters along with their type and token frequencies is provided in Table 4.

CLUSTER	TYPE	TOKEN	CLUSTER	TYPE	TOKEN	CLUSTER	TYPE	TOKEN
ſt	1261	1 802 222	kv	144	115 613	sn	8	2 079
pr	754	891 411	ſpr	126	204 499	tj	8	2 079
ſp	648	708 589	ſr	121	260 420	skr	8	1 125
gr	619	838 145	ſn	114	109 475	str	6	6 528
fr	599	1 001 796	ſm	99	58 474	fj	6	6 528
kr	569	48 5619	kn	98	82 839	sr	6	5 656
tr	538	570 454	sk	80	43 767	tv	5	1 092

br	458	492 293	pfl	53	29 843	vr	4	1 570
kl	429	463 396	st	45	34 697	skv	4	1 437
ʃtr	370	300 725	sl	28	15 198	skl	3	1 081
dr	324	402 423	ps	27	13 575	ʃpl	3	693
ʃv	312	306 218	sv	14	9 041	sf	2	316
fl	300	210 850	sm	14	7 646	gm	2	291
ʃl	292	273 296	sp	13	6 604	pn	1	239
bl	248	285 319	ks	10	3 831	ʃk	1	175
gl	247	246 355	bj	10	3 831	km	1	175
tsv	235	632 124	gn	10	2 822	spl	1	163
pl	188	256 185	sts	9	17 844	pfr	1	134

Table 4. Type and token frequencies of CC and CCC clusters (based on Wiese & Orzechowska *in review*).

3.2. Methodology

The analysis to follow involves several types of markedness indices. Firstly, we determine the preferability status of cluster types (preferred and dispreferred) based on whether they follow the well-formedness hypotheses in (2). This binary classification makes it possible to observe the general structure of initial clusters in German in terms of NAD, and compare it to the predictions made by the SSG. We will be able to show that an intricate patterning of several types of distances that enter the calculation matrix in NAD makes different predictions regarding cluster markedness than sonority-related measures, which are based on manner distances.

Second, apart from a binary division into preferred and dispreferred clusters, we provide their gradient classification based on NAD product values. This scalar grouping shows the distribution of cluster types on a continuum of phonotactic preferability merging between two extremes of the most and the least preferred types. Such a detailed classification enables a comparison with the accounts, in which sonority distances are employed to determine cluster status.

Finally, we are interested in observing the relationship between different types of NAD indices and frequency values, as specified in (3).

- (3) Types of correlations studied
- a. frequencies in relation to binary preferability, i.e. preferred vs dispreferred;

- b. frequencies in relation to scalar preferability, i.e. NAD product values ranging from the most preferred (dist=6) to the least preferred (dist=-5);
- c. frequencies in relation to specific NAD indices, i.e. place and manner distances (dist=0-5); S/O distances (dist=0 or 1).

Four types of frequencies will be tested: word types, word tokens and their logarithmic scales (log10). The analysis starts with the presentation of descriptive statistics based on binary preferability and scalar preferability. Next, we present a linear regression analysis, where we examine the relationship between different frequency measures and (3a) binary preferability, (3b) scalar preferability and (3c) individual distance indices.

3.3. Results

3.3.1. Binary preferability

The distances for each cluster type were computed using the NAD calculator (Dziubalska-Kořaczyk *et al.* 2014), which is an online tool performing automatic calculations. Figure 1 shows the preferability status of two- and three-member clusters. Sequences which follow and violate the hypotheses in (2) are classified as preferred ('pref') and dispreferred ('dispref'), respectively.

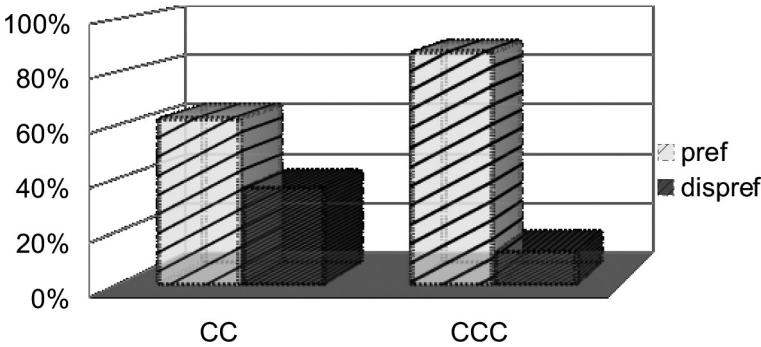


Figure 1. The distribution of preferred and dispreferred cluster types in two size groups.

Generally, 67% of clusters (= 36 types; 29 CC, 7 CCC) are preferred. 57% of all CCs and 88% of all CCCs follow the well-formedness conditions. Clusters subsumed under each category are listed in Table 5. Preferred CCs are mainly composed of an obstruent and a sonorant, while the group of dispreferred CCs primarily includes obstruent + obstruent sequences. This division goes in line with the predic-

tions made by the SSG and the sonority scale in (1). On the contrary, the status of /s/CC and /ʃ/CC sequences differs substantially in the two approaches. 7 out of 8 CCCs are preferred in terms of NAD. The unmarked status of these clusters in German results from the distribution of distances C1-C2, C2-C3, C3-V in accordance with the hypotheses in (2b).

CLUSTER	PREFERRED	DISPREFERRED
CC	bj bl br dr fj fl fr gl gm gn gr kl km kn kr pfl pfr pl pn pr sl sm sr jl jm jr tj tr vr	ks kv ps sf sk sn sp st sts sv ʃk ʃn ʃp ʃt ʃv tsv tv
CCC	skl skr spl str ʃpl ʃpr ʃtr	skv

Table 5. A list of preferred and dispreferred CC and CCC cluster types.

The binary division was used to test the relationship between cluster preferability, and type and token frequencies. The first division was based on types. 54 clusters were ordered according to their decreasing type frequency, and then split into three groups (each containing 18 types), which correspond to high, mid and low frequency bands, as shown in Table 6. For each tercile, the preferred and dispreferred types were observed. This same procedure was applied to the division based on token frequency.

CLUSTER	TYPE FREQUENCY			TOKEN FREQUENCY		
	PREF	DISPREF	FREQ. RANGE	PREF	DISPREF	FREQ. RANGE
high (18)	14	4	1261 - 188	14	4	1802222 - 246355
mid (18)	9	9	144 - 9	10	8	210850 - 5656
low (18)	13	5	8 - 1	12	6	3831 - 134

Table 6. The distribution of preferred and dispreferred clusters in three frequency bands for types and tokens.

The Pearson's Chi-squared test yielded non-significant results: p -value = 0.1738 for types, and p -value = 0.3679 for tokens. Given the significance levels, the null hypothesis on a lack of a relationship between binary preferability and different frequency measures cannot be rejected. That is, cluster preferability expressed by a two-fold division (preferred vs dispreferred) does not differ significantly for each tercile,

demonstrating that cluster status is not a relevant predictor of frequency. Further analyses involve more refined descriptive criteria of NAD.

3.3.2. Scalar preferability

The degree, to which clusters follow the hypotheses in (2), was measured using the online NAD calculator. NAD product, as an index of preferability, states an ultimate distance for a CC(C)V sequence. Table 7 presents the ranking of all clusters based on decreasing NAD product values (ranks 1-32). The larger the distance, the more preferred the cluster. A negative NAD product value indicates a dispreferred cluster.

RANK	NAD PRODUCT	CLUSTER	RANK	NAD PRODUCT	CLUSTER
1	6	bj	17	1.3	gn, kn
2	5	tj	18	1	pn, pfl
3	4.6	br, pr	19	0.5	fl, jl, jm
4	4.5	fj	20	0	sl, sm
5	4.35	ʃpr	21	-0.5	ʃn
6	4.1	str	22	-0.85	skv
7	3.85	ʃtr	23	-1	sn
8	3.6	dr, pfr, tr	24	-2.2	kv
9	3.1	fr, vr	25	-2.7	ks
10	2.6	sr	26	-3	ps
11	2.4	skl	27	-3.5	ʃp, tv
12	2.3	gl, gm, gr, kl, km, kr	28	-3.7	sk
13	2.25	spl	29	-4	sp, ʃv, tsv
14	2.15	skr	30	-4.2	ʃk
15	2.1	ʃr	31	-4.5	sf, sv, ʃt
16	2	bl, ʃpl, pl	32	-5	st, sts

Table 7. A rank order of cluster preferability based on NAD product values.

Generally, 32 ranks of preferability can be distinguished in German initial clusters. The most preferred end of the continuum (i.e. ranks 1-4) is represented by SSG-obeying sequences, namely plosive + glide, plosive + liquid and fricative + glide. The least preferred extreme (i.e. ranks 24-32) encompasses universally dispreferred obstruent clus-

ters. Note that CCCs are found in the group of preferred sequences, and occupy ranks 5-16. When NAD product values are grouped into whole numbers {6, 5, 4, ..., -3, -4, -5}, $\text{dist} = 2$ is best represented (i.e. 14 types: /bl, ʃpl, pl, ʃR, skR, spl, gl, gm, gR, kl, km, kR, skl, sR/). In this set, with the exception of /skl/, clusters are composed of an obstruent followed by a sonorant (nasal or liquid), which is an expected pattern to be found in CCs.

In order to determine the relevance of individual NAD indices in predicting different frequency measures, we ran a number of linear regressions. The frequency data do not follow the symmetric Gaussian distribution. A classic way of dealing with such heavy-tailed data is to perform the Box-Cox transformation, which makes it possible to transform both types and tokens into a normal-like shape resembling a bell curve.

In statistical modelling, the following variables were used. Type frequency and Token frequency (raw and logarithmic) were coded as dependent variables. Several word-internal independent variables can be grouped into three types (for details see Appendix):

- (4) Independent variables tested in the study
 - a. distances for each pair of segments, i.e. MOA(C1C2), POA(C1C2), S/O(C1C2), MOA(C2V), S/O(C2V);
 - b. distances summated for each pair of segments, i.e. NAD(C1C2), NAD(C2V);
 - c. NAD product.

We ran a number of linear regressions for each subset of the predictors (4a) through (4c) using the *R* language (R Core Team, version 1.1.456, Vienna, AT). The best model was selected on the basis of adjusted R^2 and the Akaike Information Criterion (AIC).

The optimal model for Type frequency is reduced (according to the standard step-wise procedure). The independent variables that contribute to this model involve MOA(C1C2) and MOA(C2V), as summarized in Table 8.

Call:					
lm(formula = boxCoxVariable(Type) ~ MOA(C1C2) + MOA(CV), data = data_type)					
Residuals:					
Min	1Q	Median	3Q	Max	
-540.0	-312.0	-129.9	106.6	2763.7	
Parametric coefficients:					
	Estimate	Std. Error	t-value	Pr(> t)	
Intercept	-731.5	426.3	-1.716	0.0922	.
MOA(C1C2)	264.4	109.5	2.415	0.0194	*
MOA(CV)	191.2	94.4	2.026	0.0481	*
—					
Residual standard error: 549.7 on 51 degrees of freedom					
Multiple R-squared: 0.1065, Adjusted R-squared: 0.07146					
F-statistic: 3.039 on 2 and 51 DF, p-value: 0.05661					

Table 8. Linear regression for type frequency.

Each independent variable is statistically significant, and both are jointly significant (F-statistic; p -value = 0.057).⁵ However, the results of the Student’s t-test and the Fisher–Snedecor test cannot be considered as precise due to the lack of normality in residuals. The non-normal distribution is indicated by the Shapiro Wilk normality test (p -value < 0.0001). Also, Figure 2 shows that the data do not follow a linear pattern. The dots represent the actual data points (type frequencies). The largest deviation from the diagonal line is found in the top right corner on the plot: the dot represents the most frequent / t / cluster.

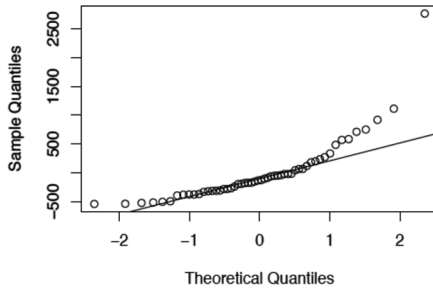


Figure 2. A graphic representation of degree of normality.

It must be emphasized that the reduced model in Table 8 is better-fitted than any other model tested. For example, a full model that includes all the variables (4a-c) is statistically non-significant (F-statistic; p -value = 0.062), and so are the variables. Moreover, there are premises to consider the model in Table 8 to be better compared to a model in which NAD product serves as the only factor, which is shown in Table 9 (p -value in ANOVA = 0.017). These findings reveal that NAD product is not a relevant predictor of type frequency, and that frequency values are correlated with the manner of articulation distances.

Model 1: boxCoxVariable(Type) ~ MOA(C1C2) + MOA(CV)							
Model 2: boxCoxVariable(Type) ~ NAD product							
	Res.Df	RSS	Df	Sum of Sq	F	Pr(> t)	
1	51	15412526					
2	52	17249354	-1	-1836828	6.0781	0.01709	*

Table 9. Analysis of variance ANOVA for type frequency: a comparison between the optimal model in Table 8 and a one-variable model.

Additionally, a non-parametric modelling using the ‘bootstrap’ method makes it possible to estimate the coefficients of the model in Table 8 in spite of the non-normal distribution of residuals. The analysis shows that in a model with MOA(C1C2) and MOA(CV) as independent variables, only MOA(C1C2) is statistically significant (p -value = 0.05). Thus, it can be concluded that, first, there is a relationship between MOA(C1C2) distance and type frequency, and, second, an increase in MOA(C1C2) results in an increase in type frequency.

As regards Token frequency, the analysis did not yield statistically significant results. Although the best model includes MOA(C1C2) and NAD(CV), its results are not better compared to a model in which no independent variables were coded (p -value in ANOVA = 0.173), and in which only NAD product was included (p -value in ANOVA = 0.064). The comparison of the models is presented in Table 10 and Table 11, respectively.

Model 1: Token ~ MOA(C1C2) + NAD(CV)							
Model 2: Token ~ 1							
	Res.Df	RSS	Df	Sum of Sq	F	Pr(> t)	
1	51	9.6449e + 12					
2	53	1.0331e + 13	-2	-6.8606e + 11	1.8139	0.1734	*

Table 10. Analysis of variance ANOVA for token frequency: a comparison between a model with two variables and a model with no variable.

Model 1: Token ~ MOA(C1C2) + NAD(CV)							
Model 2: Token ~ NAD product							
	Res.Df	RSS	Df	Sum of Sq	F	Pr(> t)	
1	51	9.6449e+12					
2	52	1.0321e+13	-1	-6.7568e+11	3.5728	0.06442	*

Table 11. Analysis of variance ANOVA for token frequency: a comparison between a model with two variables and a model with one variable.

Moreover, the results for Token frequency are not reliable due to a non-normal distribution (p -value < 0.0001), suggesting that there are no language-internal correlates of token frequency.

We ran statistical tests including the NAD(C2C3) distance in three-member clusters. The inclusion of this variable did not contribute to any model. Similarly, regression analyses run on logarithmic frequencies as dependent variables yielded worse results compared to raw types and tokens (i.e. higher AIC).

4. Discussion

The goal of this paper was to investigate the relationship between different types of frequency measures and the markedness of word-initial clusters in German. For the purpose of the analysis, we selected Net Auditory Distance; a principle that uses several criteria to evaluate the degree of cluster preferability. The criteria are represented by auditory distances pertaining to the place of articulation, manner of articulation, and laryngeal contrast. The frequencies employed in the present work involved raw types and tokens as well as logarithmic frequencies. The study has demonstrated that the manner of articulation distance between adjacent consonants in a cluster is positively correlated with the type frequency of such a cluster: an increase in MOA(C1C2) is accompanied by an increase in a number of word types featuring an initial cluster. The findings of this study contribute to two major themes addressed in phonological research, namely the phonotactic potential of a language and phonological primitives relevant for the description and classification of cluster inventories.

4.1. Structure of the lexicon and usage

First of all, we have demonstrated that the manner distance between a pair of consonants is correlated with raw type frequency. The

number of words starting with a consonant cluster increases along an increase in the distance between C1 and C2 in such a cluster. As shown in Table 8, an increase in MOA(C1C2) by one involves an increase in type frequency by 264.

A closer comparison between the preferability ranking in Table 7 and type/token frequencies in Table 4 has revealed that cluster preferability in terms of NAD is not necessarily correlated with frequency. Some high frequency clusters are not only disfavoured (negative NAD product values), but are also found at the least preferred end of the preferability continuum. For instance, /ʃt/ displays a much larger C2V distance than C1C2 distance, and is therefore ranked at the least preferred extreme of the scale (rank 31 out of 32), in spite of its high frequency. The result for this particular cluster poses problems for usage-based approaches (see Bybee 2001) as it fails to support the prediction that structural well-formedness is reflected in high use frequency. However, with the exception of /ʃt/, the top of the frequency list primarily hosts clusters that follow the well-formedness conditions in (2a-b). Although no correlation has been found between NAD product values and different frequency measures for all the clusters under investigation, top 10 cluster types are preferred (NAD product values range from 2.3 to 4.6 out of 6). Plosive + /R/ and plosive + /l/ are characterized by a stronger C1C2 binding (=larger distance) compared to a C2V binding (=smaller distance). Overall, these observations suggest that high frequency items represent the most typical structure in the language, in spite of a heavy tail of less frequent and infrequent cluster types (for similar ideas on nonlinear distributions see Kretzschmar 2015).

Moreover, we have identified a relationship neither between place distances and type frequency, nor between laryngeal distances and type frequency. In fact, these indices did not contribute to any statistical model. Neither POA(C1C2), the S/O distinction nor distances summated for each pair of segments (i.e. NAD(C1C2) and NAD(C2V)) are correlated with frequency. This finding lends support to the general sonority scale proposed for German (Wiese 1988; Hall 1992), which makes a distinction between segments only in terms of the manner classes (compare with more detailed scales in, among others, Vennemann 1988; Parker 2002; Basbøll 2005).

The results of this study are coherent with other contributions on the topic. Wiese & Orzechowska (*in review*) used the same dataset to investigate the relationship between type and token frequencies of clusters and 15 parameters expressing structural, phonetic and phonological properties of the clusters (see Orzechowska & Wiese 2015 for a detailed exposition). The parameters included, among others, size and

segmental resolvability of a cluster, the number and position of labial, coronal and dorsal C, proportion of obstruents to sonorants, increase/decrease in articulatory opening, and voice agreement. The computation of place, manner (sonority) and voice distances diverged from the analysis presented in this paper. The results of linear regression revealed a correlation between logarithmic frequencies (both types and tokens) and only two factors tested, namely sonority distances and voicing agreement between adjacent consonants. The authors reported that an increase in sonority distance entails an increase in logarithmic type and token frequencies, demonstrating that clusters with the largest sonority distances are most frequent. Moreover, it was shown that total voice agreement (i.e. voiced + voiced, voiceless + voiceless in CC) and partial voice agreement found in all CCC clusters lower frequency, i.e. clusters displaying no voice agreement have higher frequency values. Wiese & Orzechowska (*in review*) suggest that, at least in German word-initial phonotactics, structure and usage are largely independent; they “constitute two separate domains for which distributions may not have to coincide”.

The present analysis has incorporated a different set of factors, but the general conclusions overlap with the conclusions in Wiese & Orzechowska (*in review*). We have shown that out of eight predictors used in the regression analysis, only MOA(C1C2) is positively correlated with type frequency. That is, frequency values are higher for larger manner distances, as reported in the previous study. In contrast to Wiese & Orzechowska (*in review*), where voicing was shown to be correlated with frequency, the NAD-based analysis has identified no influence of the S/O distinction on frequency. In general, in the present study we have gathered further evidence in favour of the claim that there might exist a weak relationship between structure and usage.

The correlation between frequency and markedness in terms of NAD was investigated in a number of cross-linguistic studies, leading to comparable results. For instance, a dictionary- and corpus-based study in Zydorowicz *et al.* (2016) asked whether cluster preferability expressed in binary terms (i.e. preferred vs dispreferred based on the conditions in (2)) is correlated with cluster frequency in English and Polish. The data on Polish did not lend full support to the hypothesis. The analysis revealed that both preferred and dispreferred clusters occupy the highest frequency ranges in word-initial and final positions. The extension of the analysis was proposed in Orzechowska & Zydorowicz (2019), where degrees of preferability based on NAD product values were tested. Again, no straightforward relationship was observed between logarithmic type and token frequencies and scalar NAD distances.

Note, however, that the empirical data lend support to the prime role of frequency in language processing and learnability in German. Celata *et al.* (2015) and Ulbrich *et al.* (2016) demonstrated that frequency and exposure facilitate neuro-cognitive processes in German speakers. First, high frequency phonotactics is processed faster, and is less frequently hit by errors. Second, greater exposure facilitates the learnability of novel clusters. Similar observations were made in child language. For instance, infants were reported to listen longer to frequent syllables (Jusczyk *et al.* 1994) and to use phonotactic probabilities to segment the continuum of speech (Mattys & Jusczyk 2001). Research on learning models led to similar conclusions. Vitevitch *et al.* (1999) showed that nonce words with high probability phonotactics in spoken language evoke shorter processing times in English speakers than items composed of (sequences of) segments with lower frequency. This observation was confirmed in Vitevitch & Luce (1999), whose study revealed positive effects of high neighbourhood density on the processing of spoken stimuli. Thus we conclude that frequency is a critical factor for some language domains such as perception, production and processing. However, the core structure of the lexicon, at least in German, is primarily motivated by phonological factors.

4.2. The role of individual distances

The findings have demonstrated that MOA(C1C2) is the key predictor of frequency, and can be considered as the most relevant criterion in determining the preferability status of initial cluster types available in German. Place and laryngeal features do not contribute to cluster structure, which provokes the following questions: What is the basis for invoking the two criteria in the well-formedness hypotheses whatsoever? How do they contribute to the NAD principle and the description of German phonotactics?

Although place and laryngeal distances are not predictors of type and token frequencies in German, there are premises to assume that further detailed studies can reveal a predominant role of other NAD distances. There is a body of evidence demonstrating that phonological features that motivate the structure of cluster inventories, as in the present case of word onsets, differ from phonological features that regulate language functions such as perception, production, online processing or language acquisition.

Orzechowska (2016, 2019) provided evidence in favour of the relative weight of place, manner and voice features in consonant clustering. Phonotactic constraints and preferences are encoded in weighted fea-

tures specific to a word position in which a cluster occurs and a linguistic function activated. For example, Orzechowska (2019) demonstrated that the core structure of word-initial clusters in Polish is primarily motivated by non-stridency and voicing (e.g. [+voice]). In turn, the perception and production of such clusters was shown to be affected by other sets of feature patterns and principles. Accurate production in adult spontaneous speech is motivated by cluster size and the directionality of the tongue movement: CCs and clusters whose articulation involves a uniform movement towards the front or back of the mouth cavity tend to be retained in speech. In turn, auditory processing is facilitated by place-related patterns. That is, clusters characterized by large place distances between consonants, represented by a combination of labial and dorsal articulation (e.g. /px gb/) are the most perceptible sequences and cognitively less costly compared to strings of consonants articulated in the same or neighbouring articulatory regions.⁶

These results have an association with other studies which demonstrated the relevance of place rather than manner features in language production and perception. In Fikkert & Levelt's (2008) study on non-adjacent consonant harmony in early phonological acquisition, Dutch infants were reported to favour labial consonants at the left edge of the word, and dorsal consonants at the right edge in C1VC2 monosyllables. As a result, the target word /kɪp/ 'chicken' is realized as /pɪk/. Such differences are related to the relative phonetic (place and manner) salience of segments. Baroni (2014a,b) recorded responses of Italian and Dutch speakers to plateau clusters, and observed that subjects performed better at identifying the left-most consonant in a sequence when it was acoustically more salient than the prevocalic consonant. Since the status of plateau clusters is generally assumed to be sonority-violating, the study revealed that cues other than the sonority principle affect speakers' performance. These observations suggest that further research on German phonotactics focusing on different word positions and investigating linguistic competence might reveal the functional role of other types of NAD indices. Such research would be also relevant in the light of the findings in Carden *et al.* (1981), who showed that perceived place of articulation depends on perceived manner of articulation.

Further support to the relative importance of place and manner phonetic distances was provided in Baumann & Wissing (2018). The authors inspected the role of NAD distances in different sets of data. First, it was shown that the manner distances have a prime role in motivating phonotactic systems of Afrikaans and Dutch. While the manner of articulation represents the strongest selection pressure in the languages under scrutiny, phonation and place of articulation have a less clear

effect. More specifically, large MOA differences between consonants were shown to contribute to clusters' preservation from the perspective of diachrony and language acquisition, while large POA differences have the opposite effect on the structure of cluster inventories. Baumann & Wissing's (2018) observations on POA distances diverge from the present statistical results which have revealed no correlation between place indices and the frequency measures. The lack of such a relationship can be attributed to the phonotactic patterns in the respective languages, to the very characteristics of some place features (e.g. see the discussion on 'r' variants in Section 2.2.4.), and to the method of measuring distances. An answer to this question could be provided in a systematic typological comparison, which is outside of the scope of the present paper.

The aforementioned cross-linguistic findings based on clusters drawn from dictionaries and corpora yielded results largely comparable to the present study. That is, the manner of articulation is critical for the structure of cluster inventories, and the ensuing lexical potential of the languages. As a consequence, it can be posited that in German perceived manner distances are larger and clearer compared to perceived place distances. Moreover, the results go in line with contributions on the role of manner features in constructing consonant inventories across the languages of the world (e.g. Clements 2001), and with approaches in which the manner of articulation constitutes the structural core of phonological units (e.g. Steriade 1993; Schwartz 2013).

4.3. Implication for phonotactic models

Our findings support sequencing principles that employ the concept of sonority distance, although the way of computing manner distances varies across the accounts. Nevertheless, what emerges from the previous studies (e.g. Clements 1990; Selkirk 1984) and the present analysis is that sonority distances constitute an important methodological measure in the study of the phonological structure of consonant clusters. Moreover, the preference for large contrast reflects one of the hypotheses in Natural Phonology, namely the clarity of perception, in opposition to the ease of articulation. Generally, fortitions enhance perceptual salience, while lenitions serve fluent production. This principle is embedded in NAD in the rankings of clusters: the larger the NAD product value, the better the cluster. Generally, although we have pointed out that only the MOA(C1C2) distance is correlated with frequency, the regression model in Table 8 also accounts for MOA(CV). Note that the sonority scale in German involves four consonant classes plus vowels, which means that a maximum distance of four holds between C1C2 (i.e. plosives and glides

in either order), and a maximum distance of five defines the CV interface (i.e. plosives and vowels in either order). It can thus be concluded that top frequency clusters tend to maximize MOA(C1C2), at the same time ensuring sufficiently large MOA(CV) distances. This pattern supports some models on perception and production.

The CV transition is the best acoustically and physically grounded sequence of sounds in human speech. It represents an alternation of a quieter and louder sound, which is most salient and reflects a natural frequency of the jaw (Maddieson 1999). Acoustically, large modulations are more likely to be preserved in a language (Ohala 1990). Dziubalska-Kołaczyk (2009, 2014) interprets this fact as a universal preference stating that distance between two consonants must be sufficiently large for a cluster to be preserved. This point was also made in a study on Italian and Dutch casual speech reductions in Baroni (2014a,b), who demonstrated that the more salient a consonant, the easier it becomes for listeners to be perceived correctly as the first member of an initial plateau cluster and as the last member of a final plateau cluster. Dutch and Italian listeners performed better at identifying the most peripheral consonants in clusters when these consonants were more salient compared to other consonants within the same sonority class. For example, word initial /mn/, /rl/ and /sf/ were recognized more accurately than /nm/, /lr/ and /fs/. The same pattern was observed in spontaneous speech: both groups of speakers showed a preference for preserving highly salient material (in particular sibilants and rhotics). Although Baroni (2014b) employed somewhat altered NAD distance measures (after Baroni 2012), generally the results point to the relevance of the most marginal segment in a cluster. This observation is captured by the distance matrix in Dziubalska-Kołaczyk (2002, 2009, 2014). For instance, in CCV, the marginal C1C2 sequence should display larger contrast compared to C2V, as captured in the hypothesis $NAD(C1,C2) \geq NAD(C2,V)$.

Note that type frequency is associated with the phonotactic potential of the lexicon. Thus the results of the present study have revealed that the manner of articulation as a consonantal primitive, and a well-defined distribution of MOA distances as a phonotactic primitive are key for the core structure of clusters available in German. Naturally, this finding suggests a certain direction through which the inventory of clusters has developed in the course of time (see Baumann & Wissing 2018 for similar results) and through which it can be expanded. For instance, onomastic phonotactics constitutes an interesting case of the possible expansion of the phonotactic inventory of a language.

4.4. Some reflections on onomastic phonotactics

Generally, proper nouns “constitute in some ways a special subset of the lexicon” (Cutler *et al.* 1990: 472): they function independently compared to other words present in the language’s lexical stock. Such phonological differences were reported cross-linguistically. For instance, Jaskuła (2019) and Jaskuła & Szpyra-Kozłowska (2020) showed that Polish place names contain initial and final clusters which are either absent in common words, or found only in isolated examples. In English, Cutler *et al.* (1999) found systematic phonological differences between male and female names: women’s names tend to be longer, begin with an unstressed syllable, and contain the high front vowel /i/. Also Kunze (2003) emphasized that syllable structure in German is affected by names that have different donor languages. Thus, loanwords must undergo a preselection stage, ensuring that they are either modified to match native phonotactics or simply rejected.

This preselection stage should eliminate a number of initial clusters such as sonorant + sonorant, sonorant + obstruent or geminates, which in fact are listed in the Duden phonetic dictionary (2009). For instance, *Nguyễn-Du* (Vietnamese), *Nkrumah* (Ghanian), *Mladenovac* (Serbian), *Rtischschewo* (Russian) violate the core O + S onset structure in German, and are thus likely to be repaired by native speakers by vowel insertion. The inclusion of such clusters into the present study would most likely affect the results. First, S + O + V sequences display a larger C2V distance, violating the well-formedness conditions in (2a). Second, the items are low frequency compared to the regular lexical stock. In consequence, the data would contain a heavy tail of infrequent and dispreferred types. Therefore, for the time being we leave the phonological analysis of onomastic clusters as a possible theme of our future investigation.

4.5. Further extensions of NAD

Given the relevance of the manner of articulation distances in shaping the structure of word-initial consonant clusters in German, other types of distances could be considered in the calculation procedure in NAD. For instance, areas of further refinement could involve the inclusion of additional manner features such as stridency or continuance, and vowels of different height. Our future work will involve exploring the relationship between frequency and structure in German using clusters found in different word positions, and employing different statistical methods. It would be of interest to run analyses which would unveil the relative importance of specific NAD indices, possibly leading to the refinement of place and manner categories employed in the calculation procedure.

5. Conclusions

The goal of the paper was to investigate the relationship between usage and the markedness status of word-initial consonant clusters in German. We have used the Net Auditory Distance principle to determine the degrees of preferability of clusters. We asked which properties pertaining to the place of articulation, manner of articulation and the sonorant/obstruent distinction employed in NAD are correlated with type and token frequencies extracted from a large corpus. Overall, the analysis has revealed that the manner of articulation distances between a pair of consonants (C1C2) are positively correlated with raw type frequency: the larger the MOA(C1C2) distance, the higher the frequency. This finding suggests that the manner of articulation distance is a key force motivating the structure of word-initial clusters available in German.

Abbreviations

C = consonant; dist = distance; MOA = manner of articulation; NAD = Net Auditory Distance; O = obstruent consonant; S/O = sonorant-obstruent contrast; POA = place of articulation; S = sonorant consonant; SSG = Sonority Sequencing Generalization; V = vowel.

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Notes

¹ We would like to thank one Reviewer for drawing our attention to the deductive-nomological model of Hempel & Oppenheim (1936). The phonotactic model presented in this paper is compatible with the deductive nomological model of explanation; we start with principles (universal preferences and well-formedness conditions) and next test whether and/or to what extent the data fit the principles.

² A revised and extended version of NAD is in preparation. The revised NAD features Parker's (2008) sonority scale and therefore distinguishes among vowels. It also assigns POA values to vowels (vowel colour).

³ Morphologically motivated sequences are absent from German in word-initial position; all the clusters under investigation are phonologically motivated.

⁴ The realization of the fricative as /s/ is found in borrowings.

⁵ Although the .05 level is generally regarded as cutoff for significance, a body of research has argued that the null hypothesis significance testing is somewhat anachronistic (e.g. Wainer & Robinson 2003; Wasserstein 2016; Wasserstein *et al.* 2019).

⁶ Although the sonority profile of clusters does not affect response latencies, it is a critical factor at metalinguistic level, i.e. when phonological judgement is made.

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Gradient phonotactics and frequency: A study of German initial clusters

Appendix

Detailed NAD indices

IPA	MOA (C1C2)	POA (C1C2)	S/O (C1C2)	NAD (C1C2)	NAD (C2C3)	MOA (CV)	S/O (CV)	NAD (CV)	NAD PRODUCT	PREFERRED CLUSTER?
bj	4	2	1	7	0	1	0	1	6	yes
bl	2.5	1	1	4.5	0	2.5	0	2.5	2	yes
br	3	2.6	1	6.6	0	2	0	2	4.6	yes
dr	3	1.6	1	5.6	0	2	0	2	3.6	yes
fj	3	1.5	1	5.5	0	1	0	1	4.5	yes
fl	1.5	0.5	1	3	0	2.5	0	2.5	0.5	yes
fr	2	2.1	1	5.1	0	2	0	2	3.1	yes
gl	2.5	1.3	1	4.8	0	2.5	0	2.5	2.3	yes
gm	2	2.3	1	5.3	0	3	0	3	2.3	yes
gn	2	1.3	1	4.3	0	3	0	3	1.3	yes
gr	3	0.3	1	4.3	0	2	0	2	2.3	yes
kl	2.5	1.3	1	4.8	0	2.5	0	2.5	2.3	yes
km	2	2.3	1	5.3	0	3	0	3	2.3	yes
kn	2	1.3	1	4.3	0	3	0	3	1.3	yes
kr	3	0.3	1	4.3	0	2	0	2	2.3	yes
ks	1	1.3	0	2.3	0	4	1	5	-2.7	no
kv	1	1.8	0	2.8	0	4	1	5	-2.2	no
pfl	2	0.5	1	3.5	0	2.5	0	2.5	1	yes
pfr	1.5	2.1	1	5.6	0	2	0	2	3.6	yes
pl	2.5	1	1	4.5	0	2.5	0	2.5	2	yes
pn	2	1	1	4	0	3	0	3	1	yes
pr	3	2.6	1	6.6	0	2	0	2	4.6	yes
ps	1	1	0	2	0	4	1	5	-3	no
sf	0	0.5	0	0.5	0	4	1	5	-4.5	no
sk	1	1.3	0	2.3	0	5	1	6	-3.7	no
sl	1.5	0	1	2.5	0	2.5	0	2.5	0	yes
sm	1	1	1	3	0	3	0	3	0	yes
sn	1	0	1	2	0	3	0	3	-1	no
sp	1	1	0	2	0	5	1	6	-4	no
sr	2	1.6	1	4.6	0	2	0	2	2.6	yes
st	1	0	0	1	0	5	1	6	-5	no
sts	0.5	0	0	0.5	0	4.5	1	5.5	-5	no
sv	0	0.5	0	0.5	0	4	1	5	-4.5	no
fk	1	0.8	0	1.8	0	5	1	6	-4.2	no
fl	1.5	0.5	1	3	0	2.5	0	2.5	0.5	yes

[m	1	1.5	1	3.5	0	3	0	3	0.5	yes
[n	1	0.5	1	2.5	0	3	0	3	-0.5	no
[p	1	1.5	0	2.5	0	5	1	6	-3.5	no
[r	2	1.1	1	4.1	0	2	0	2	2.1	yes
[t	1	0.5	0	1.5	0	5	1	6	-4.5	no
[v	0	1	0	1	0	4	1	5	-4	no
[j	4	1	1	6	0	1	0	1	5	yes
[r	3	1.6	1	5.6	0	2	0	2	3.6	yes
[sv	0.5	0.5	0	1	0	4	1	5	-4	no
[v	1	0.5	0	1.5	0	4	1	5	-3.5	no
[r	2	2.1	1	5.1	0	2	0	2	3.1	yes
[skl	1	1.3	0	2.3	4.8	2.5	0	2.5	2.4	yes
[skr	1	1.3	0	2.3	4.3	2	0	2	2.15	yes
[skv	1	1.3	0	2.3	2.8	4	1	5	-0.85	no
[spl	1	1	0	2	4.5	2.5	0	2.5	2.25	yes
[str	1	0	0	1	5.6	2	0	2	4.1	yes
[pl	1	1.5	0	2.5	4.5	2.5	0	2.5	2	yes
[pr	1	1.5	0	2.5	6.6	2	0	2	4.35	yes
[tr	1	0.5	0	1.5	5.6	2	0	2	3.85	yes