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Measuring the phonological (un)naturalness of selected alternation patterns in Polish

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ABSTRACT

In most generative research phonological naturalness/markedness has served as a synchronic bias that can explain the predominance of certain patterns in the world's languages. In this paper, on the basis of one language, Polish, it is shown that unnatural patterns are far from rare and, therefore, phonological theories need to accommodate them. The two patterns under scrutiny, consonant mutations and progressive devoicing, are to a large degree unnatural but fully productive. Consonant mutations are subjected to a thorough examination using data from 604 outputs of the concatenation of 27 mutation-triggering suffixes, both vowel- and consonant-initial, in order to assess the role of various predictors of palatality. As there is no observable effect of naturalness but a strong influence of specific suffix-initial segments, base-final consonants and individual suffixes on the palatality of the output, the data provide support for a framework that does not incorporate phonological naturalness as an active bias in models of grammar. The morphophonological patterns, formalized as source-oriented schemas, are morpheme specific. This discussion provides evidence for a model of grammar comprising multiple morpheme-specific cophonologies.

1. Introduction

Most phonological accounts identify phenomena that are cross-linguistically common and attempt to find a basis for them. When the basis for a phonological process can be found in phonetics, such a process is classified as phonologically natural. Because they result from phonetically based sound changes, phonologically natural processes are very common (Blevins, 2004, 113–117). However, also attested are processes that are phonologically unnatural. They are typologically less common or even specific to one particular language. We focus on two such processes in Polish. First, we look at consonant mutations. An in-depth quantitative analysis suggests that naturalness does not play a decisive role in their conditioning. Palatality of the output consonants overwhelmingly depends on the individual segment that follows and the base-final consonant, as well as on the following suffix. In comparison, the backness of the following vowel (or consonant) appears to be a poor predictor of palatality. Progressive devoicing furnishes another example of a pattern which contradicts the predictions of a model invoking naturalness. On the theoretical front, the discussed patterns are used as evidence for morpheme-specific schemas which make no reference to phonological naturalness.

This paper is structured as follows. In Section 2, I discuss the concept of naturalness/markedness and its role in phonology. Section 3 provides evidence from past research for the existence of unnatural patterns in the world's languages. In Section 4

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we turn to Polish. Sections 4.1–4.3 focus on phonologically unnatural patterns in Polish: consonant mutations and progressive devoicing. The quantitative analysis of consonant mutations in Section 4.2 is based on the data from 27 mutation-triggering suffixes and their impact on 32 base-final consonants. The 604 outputs of mutations are then subjected to statistical tests to establish the relative importance of various predictors for the palatality of the resulting consonant. Sections 5.1–5.3 lay out the main assumptions and represent the discussed patterns in a model of phonology and morphology that allows reference to morphosyntactic information and is not based on phonological naturalness. Section 5.4 outlines the implications of the analysis for phonological and morphological theories. Section 6 provides conclusions.

The main contribution of the present paper is that it adduces quantitative evidence for phonologically unnatural and morphosyntactically restricted patterns. An analysis that uses quantifiable data produces testable results and avoids a bias that is often an artifact of the theoretical framework espoused by a researcher. The analysis suggests that unnatural patterns are an important part of the typology of phonological alternations and every psychological model of phonology and morphology has to accommodate them.

2. Naturalness and phonological theory

Phonologically natural processes are those that have a phonetic motivation, that is, they result from the physical constraints of speech production and perception (Hansson, 2014, 319). For example, palatalization before front vowels is phonologically natural because it results from C-to-V coarticulation (Kochetov, 2011). Conversely, palatalization before back vowels is phonologically unnatural because it lacks such an articulatory motivation. Hansson (2014, 319) observes that "common phonological processes usually have clear parallels in low-level patterns of phonetic variation". The existence of this link between synchronic patterns and phonetics leads to the fundamental question whether phonetic factors should be incorporated in our models of synchronic grammars. In other words, should phonological theories include reference to phonetic conditioning or should phonetic conditioning be relegated outside grammar? There are two views on this issue in current phonological theories. Mainstream generative phonology generally holds that phonetic substance shapes synchronic phonological systems and should play an active role in them. According to the opposing view, diachronic explanations, which by default reference phonetic conditioning, are sufficient in providing explanations for synchronic patterns; grammar-internal explanations for the same patterns are redundant and misguided. Let us consider these two views in more detail.

The issue of naturalness has been present in generative research since its conception. The discussion in Chapter 9 of *the Sound Pattern of English* (Chomsky and Halle, 1968) was prompted by the general concerns that the formal mechanisms proposed to account for linguistic patterns were too powerful and could not distinguish between phonologically natural (typologically common) and unnatural (rare) processes. Chomsky and Halle (1968) assert that phonological naturalness is an important factor in determining which processes can be stated as rules and which cannot. Specifically, rules that increase the markedness of structures are predicted to be impossible. In other words, Chomsky and Halle observe that their model largely overpredicts the types of processes that occur in natural languages and propose to constrain the set of possible rules by appealing to phonological markedness. The notion of naturalness/markedness was later incorporated in autosegmental phonology (Goldsmith, 1976) and feature geometry (Clements, 1985; Sagey, 1986). In the latter theory, for example, hierarchical organization of features mirrors the structure of the vocal tract. In this way, phonetically natural processes can be stated in terms of simple operations, while phonetically unnatural processes require complex and arbitrary mechanisms or cannot be stated at all.

In Optimality Theory (Prince and Smolensky, 1993/2004) naturalness is encoded by means of phonetically grounded markedness constraints. For example, the susceptibility of certain positions within a string of segments to contrast neutralization (e.g. neutralization of voice specification in preconsonantal and prepausal positions) results from the decreased salience of acoustic cues in these positions. Such correlations are stated in terms of markedness constraints that reference phonetic information (e.g. the availability of phonetic cues in a particular position). Markedness constraints are either innate (Prince and Smolensky, 1993/2004) or induced from experience with a language (Hayes and Steriade, 2004). Crucially, in both approaches, markedness constraints are universal.

Approaches that incorporate phonetic content into synchronic grammars predict that naturalness should play an important role in the acquisition of a language. Specifically, thanks to universal phonetically grounded markedness constraints, unnatural processes are harder to acquire than comparable natural processes. Following Hansson (2014, 336–342), there are two possible ways in which synchronic grammars can hinder the emergence of unnatural patterns. The first way refers to the "prophylactic" effect of grammar on linguistic patterns. While natural patterns are allowed to occur, the appearance of unnatural patterns is blocked because the operations (rules or constraints) that could potentially trigger such processes are not available. According to the second, more plausible way, although unnatural patterns can arise in a language,[1] they will not be acquired by a language learner due to the constraining effect of grammar. de Lacy (2006) refers to this constraining role of grammar as straitjacket effects. Kiparsky (2008) analyzes sonority-driven stress systems. In such systems, syllables with more sonorous vowels tend to attract stress, while syllables with less sonorous vowels tend to repel it, e.g. [a] attracts stress, while [ə] repels it. According to Kiparsky (2008, 51), a system in which [ə] attracts stress, while more sonorous

[1] Such unnatural patterns may result from a series of phonetically-transparent changes, where the effects of one change are subverted by a later change, rendering the outcome phonologically opaque (e.g. through rule telescoping).

vowels repel it is impossible to learn. If such a system arose (as a result of a sound change), it would have to be reanalyzed with lexically marked stress. That is, words with a stressed [ə] would end up being marked as exceptional. Thus, grammar is responsible for sifting linguistic patterns and blocking the acquisition of unnatural ones.[2] The position that synchronic universals (i.e. markedness) constrain diachronic change and shape linguistic patterns is advocated in, for instance, de Lacy (2002, 2006), de Lacy and Kingston (2013) and Kiparsky (2006, 2008).[3]

According to the competing view, explanation for synchronic phonological patterns is situated in the diachronic dimension. Representative of this approach are Ohala (1981), Blevins (2004, 2006), Hume (2004), Haspelmath (2006), Hale and Reiss (2008) and Czaplicki (2010a, 2010b, 2013, 2014a, 2016a). More and more evidence accumulates suggesting that putative universals are in fact strong statistical tendencies, reflecting a range of extra-grammatical factors, rather than innate design features of the language faculty. Experimental results and typological studies suggest that both phonetically natural and unnatural patterns are learnable, well attested and stable (Bach and Harms, 1972; Onishi et al., 2002; Peperkamp and Dupoux, 2007). Synchronic explanations, e.g. the use of phonetically grounded markedness constraints, largely duplicate diachronic explanations and are thus redundant. Hansson (2014, 341) adequately characterizes the type of logic behind this position.

(1) Diachronic explanations of the sort advocated by Ohala, Blevins, and others are in a fundamental sense reductionist: the explanandum (some recurrent sound pattern or typological generalization) is accounted for in terms of an explanans that is based in a concrete and observable domain which is subject to known physical laws and amenable to direct experimental verification (aspects of physiology, aerodynamics, acoustics, and perception). The alternative, to posit some innate constraint or constraint family as part of UG [Universal Grammar] (or to rely on already-posited constraints in some novel ranking arrangement), locates the explanans in a domain which is itself hypothetical and essentially unobservable. With this in mind, it would seem to be sound methodology to operate under the assumption that nothing should be attributed to UG except when an adequate diachronic-functional explanation cannot be formulated.

Blevins (2004, 23) follows this line of thinking to its logical conclusion and claims that diachronic explanations for sound patterns have priority over competing synchronic explanations.

An important aspect of this diachrony-over-synchrony approach is its treatment of unnatural patterns. While such patterns are possible and attested, their rarity in relation to natural patterns results from less likely trajectories of sound changes (via rule inversion, telescoping, analogy, and other mechanisms) that might lead to their emergence. Thus, the predominance of natural patterns in the world's languages is not due to the constraining effects of grammar but to common trajectories of sound changes.

While the arguments against the role of phonetic content in phonological systems in the case of natural patterns revolve around Occam's razor (like the cited discussion from Hansson, 2014), identification and quantitative analyses of phonologically unnatural patterns should provide strong evidence one way or the other. Approaches that assume the intervention of universal grammar predict that (at least some) unnatural patterns should not be acquired because the theory lacks formal means to represent them. If it is shown that unnatural patterns are attested (though obviously less often than natural patterns), learnable and productive, this will constitute an important argument against the constraining role of synchronic grammars. If, on the other hand, phonologically unnatural patterns are indeed avoided by language learners, the intervention of grammar is necessary and the proposals of Ohala, Blevins, and others run into problems.

3. Unnatural processes and systems in past research

Phonologically unnatural processes have been brought to attention in, for example, Bach and Harms (1972). Aronoff (1994) discussed some morphological alternation patterns that are general within some word-class in a given language but for which there is no obvious "natural" explanation in terms of independently motivated features, whether phonological, (morpho) syntactic or semantic. This section provides several examples of unnatural patterns. We begin with the voicing contrast in Khasi.

[2] A reviewer argues that neither prophylactic nor straitjacket effects are automatically entailed by a theory which invokes phonological naturalness. However, a theory which assumes a synchronic bias that is allowed *not* to have any observable effects on the data encounters a problem. Such a theory is difficult or even impossible to falsify. Thus, the central assumption of the present analysis is that naturalness *must* have some measurable effect on the data in order to be accepted as a synchronic bias.

[3] A reviewer raises an important concern. Insofar as synchronic grammars consist of many constraints that regulate the emergence and maintenance of phonological processes, naturalness is just one constraint among many. On this assumption, competition among constraints may produce both natural and unnatural patterns in a language. However, in order to prove that naturalness is an active synchronic bias, its effects must be *observed* in the data. That is, we should be able to identify the constraining effects of grammar (straitjacket effects). A bias that is as a rule overridden by other constraints may be deemed redundant and called into question. Put differently, naturalness, just like any other scientific hypothesis, is testable and falsifiable. That is, naturalness can be proven false by contradicting it with an observation of some relevant data. Thus, the aim of the current paper is to establish whether naturalness has an effect on the analyzed data from Polish.

On the basis of acoustic and perceptual evidence, it has been established that the position after a vowel and before a sonorant (V__[+son]) is the most advantageous for maintaining voicing contrasts. Steriade (1999, 6) lists the following cues to voicing in this context: closure voicing, closure duration, V_1 duration, F_1 values in V_1, burst duration and amplitude, VOT value and F_0 and F_1 values at the onset of voicing in V_2. There are fewer available phonetic cues for voicing contrasts in word-final position. The most impoverished cues can be found in word-initial preconsonantal position: closure voicing and closure duration (Steriade, 1999, 6). The universal scale of voicing perceptibility in (2) reflects these phonetic facts ("≻" indicates that voicing in the context on the left of the sign is more perceptible than voicing in the context on the right).

(2) Scale of obstruent voicing perceptibility according to context (Steriade, 1999, 11)
V__[+son] ≻ V__# ≻ V__[-son] ≻ {[-son]__[-son], [-son]__#, #__[-son]}

The scale in (2) finds reflection in universally ranked constraints, given in (3). The higher ranked the constraint, the more difficult it is to maintain voicing contrast in the context it mentions. That is, the constraints are ranked in the order of inverse perceptibility.

(3) Constraints on the distribution of voicing: ranking is universally fixed by alignment to the perceptibility scale in (2) (Steriade, 1999, 11)
*αvoice / [-son]__[-son], [-son] __#, #__[-son] >>
*αvoice/ V_ [-son] >>
*αvoice/ V_ # >>
*αvoice/ V_ [+son]

Steriade (1999, 11) follows Lindblom (1990) in assuming a deductive approach to phonology adding that "the contents of the grammar are deduced from knowledge of the conditions in which speech is perceived and produced". Crucially, since the conditions of perceptibility of voicing in (2) are universal, the grammar deduced from them, that is, the constraint ranking in (3), should also be universal.

A phonological analysis incorporating the constraint ranking in (3), based on the scale in (2), makes strong predictions about the maintenance of voicing contrast according to context. Specifically, if a language allows contrast in more impoverished contexts, it should also allow contrast in positions with stronger cues. In other words, the constraint ranking in (3), based on the scale in (2), is fixed and the relations between the constraints are implicational. Suppose that Preserve[voice], a faithfulness constraint mandating preservation of voicing contrast, is ranked above *αvoice / #__[-son]. This entails that Preserve[voice] also dominates *αvoice/ V_ #. Thus, preserving contrast in positions with weaker cues implies preserving contrast in positions with stronger cues. Yet, this is not always the case. In Khasi voicing contrast is maintained in initial obstruent clusters but is lost word finally.

(4) Voicing contrast in initial clusters in Khasi (Henderson, 1992, 62)

bti	'to lead by the hand'	pdot	'throat'
bthi	'sticky'	pdeng	'middle'
dkar	'tortoise'	tbian	'floor'
dkhar	'plainsman'	tba	'feel'
dpei	'ashes'	pjah	'cold'
bshad [bʃa:t]	'civet'	bdi	'twenty'

Based on instrumental evidence, Henderson (1992) confirmed that there is no *svarabhakti* vowel between the two stops and that voicing contrast is maintained in this position. Crucially, Khasi neutralizes contrast between voiced and voiceless stops in word-final position. The Khasi pattern of voicing contrast does not follow from the universal scale of perceptibility in (2) and in this sense is phonologically unnatural.[4]

Another important prediction based on the perceptibility scale in (2) is that while final devoicing should be typologically common, an alternation pattern involving final voicing should not be attested at all. This follows from the fact that voicing contrast has universally weaker cues in word-final position than in prevocalic position. Furthermore, there is no phonetic motivation for final voicing. Yet, Blevins (2006) discusses several languages where final voicing is an active process. These include Somali and Lezgian.

[4] A reviewer points out that the Khasi pattern might be dealt with if we rank a constraint enforcing faithfulness to voicing in initial obstruent clusters above the constraint proscribing voicing contrast in clusters of obstruents. While this is certainly possible, this position entails that constraint rankings deduced from phonetic experience (i.e. voicing perceptibility in obstruent clusters) are trumped by language-specific considerations (i.e. faithfulness to word-initial pre-obstruent position). Patterns of this kind are problematic for a strictly phonetically based approach to grammar, such as the one that appeals to the fixed ranking of constraints derived from voicing contrast perceptibility. However, the current analysis correctly predicts that patterns may be language specific, as it is not constrained by phonological naturalness.

The unstressed vowel reduction in Seediq is yet another unnatural pattern worth mentioning. In this language, unstressed [e] is merged with [u], rather than with [i] (Barnes, 2006). A front vowel becomes back in unstressed syllables. Still another unnatural pattern can be found in the typology of nasal + stop clusters. While many languages show postnasal voicing, a process with sound phonetic motivation, Hyman (2001) cites evidence for a constraint against voiced stops in nasal + stop clusters in Tswana.

Phonological naturalness is also applicable to segmental inventories. Phonologically natural inventories are symmetrical (in this way, they take advantage of all available feature combinations) and tend to exploit less marked segments before more marked segments. The effect of symmetry can be seen in the inventory of Polish stops in (5a). The Dutch inventory in (5b) is not fully symmetrical because the voiced series lacks [g]. However, this gap can be explained by reference to markedness. For aerodynamic reasons, the least marked of the voiced stops is the bilabial [b]. The velar stop [g], on the other hand, is the most marked because voicing is the most difficult to sustain at that place of articulation (Ohala, 1983).

(5) Stop inventories

a. Polish
p t k
b d g

b. Dutch (Booij, 1995)
p t k
b d

c. Halh (Khalkha) Mongolian (Svantesson et al., 2005)
p pʲ t tʲ
(pʰ) pʰʲ tʰ tʰʲ
gʲ g G

The stop inventory of Halh in (5c) contains voiceless unaspirated and aspirated labial and coronal stops and voiced velar stops (allophones). Svantesson et al. (2005) confirm that the velar stop is voiced and behaves as such phonologically. The Halh inventory is problematic for accounts incorporating phonological naturalness for two reasons: (i) it is not symmetrical and (ii) it does not follow from markedness. Unlike the Dutch system in (5b), the voiced series contains the velar stop, while both the labial and dental stops are absent. Thus, the inventory contains the most marked of the voiced stops. The Halh system of stops is not natural, as there is no phonetic motivation for the presence of voiced velar stops to the exclusion of the voiced bilabial (and dental) stops. For a more detailed discussion of such gaps in sound inventories unexpected from the point of view of markedness, see Brown (2006).

4. Unnatural and morphologically restricted processes in Polish

We have seen that examples of unnatural patterns are easily available in the dynamic alternations as well as in the inventories of several languages. In this section, I provide evidence from Polish, suggesting that unnatural and morphologically restricted patterns merit a place in models of phonology and morphology. We look at two processes from Polish. For each process, we begin with a discussion of the phonetic underpinnings that a phonologically natural counterpart of the process might have and then provide evidence that such phonetic motivation is missing for specific alternation patterns. The pattern of consonant mutations is afforded a thorough investigation using quantitative data, in order to identify the major factors conditioning palatality and find out whether naturalness is one of them.

4.1. Consonant mutations

The phonetic precursor for palatalization before front vowels is consonant-to-vowel coarticulation (Kochetov, 2011). To take a concrete example, velar palatalization results from gradient fronting of [k] before [i] and has its roots both in articulation and perception. The tongue body backing for [k] and the tongue body fronting for [i] cannot be co-produced without a certain degree of coarticulatory adjustment (Hyman, 1975; Kochetov, 2011). On the perception side, fronted velars are characterized by frication at the release and this makes them acoustically similar to palato-alveolar affricates (Guion, 1996). There is ample evidence that this phonetic effect is responsible for diachronic changes in many languages that led to the shift of velars to palato-alveolars. Palatalization of coronals (e.g. t > tʃ) before front vowels results from similar phonetic considerations (Zsiga, 1993). Palatalization of labials (e.g. p > pj) does not result in assibilation (or any adjustment involving place of articulation) because the two gestures required to produce palatalized labials (i.e. labial and palatal) are physically uncoupled (Kochetov, 2011). In our discussion of palatalization, we will consider four scenarios.

(6)	a. A consonant is palatalized before a front vowel.	natural
	b. A consonant is depalatalized before a front vowel.	unnatural
	c. A consonant is palatalized before a back vowel.	unnatural
	d. A consonant is palatalized before a non-palatal consonant	unnatural

Of the four, only the first scenario is phonologically natural because it results from the phonetic effects mentioned above. The other three scenarios lack phonetic motivation. It will be shown that instances of all four types of processes are attested in Polish. Consonant mutations are fully productive and form a substantial part of Polish morphophonology (Gussmann, 2007). Therefore, conclusions reached on their basis should be central in the discussion of the organization of mental grammars and phonological theories.

Palatalization before front vowels is a very common synchronic process in Polish. Labials, coronals and velars alternate with their palatalized counterparts before front vowels (data from Gussmann, 2007).

(7)	Palatalization before front vowels	
	a. labials	
	małp-a [mawpa] ‘monkey’	małpi-e [mawpjɛ] dat.sg.
	bab-a [baba] ‘crone’	babi-e [babjɛ] dat.sg.
	raf-a [rafa] ‘reef’	rafi-e [rafjɛ] dat.sg.
	ws-i [fɕi] ‘village’ gen.pl.	wieś [vjɛɕ] nom.sg.
	b. coronals	
	wat-a [vata] ‘cotton wool’	waci-e [vatɕɛ] dat.sg.
	dni-a [dɲa] day’ gen.sg.	dzień [dʑɛɲ] nom.sg.
	los [lɔs] ‘fate’	losi-e [lɔɕɛ] loc.sg.
	skaz-a [skaza] ‘blemish’	skazi-e [skaʑɛ] dat.sg.
	c. velars	
	rak [rak] ‘crab’	raki-em [racɛm] instr.sg.
	kł-y [kwɨ] ‘tusk’ gen.pl.	kieł [cɛw] nom.sg.
	drąg-u [drɔŋgu] ‘pole’ gen.sg.	drągi-em [drɔŋɟɛm] instr.sg.
	gz-a [gza] ‘gadfly’ gen.sg.	giez [ɟɛs] nom.sg.
	ręk-a [rɛŋka] ‘hand’	ręc-e [rɛntsɛ] dat.sg.
	wag-a [vaga] ‘scales’	wadz-e [vadzɛ] dat.sg.
	much-a [muxa] ‘fly’	musz-e [muʂɛ] dat.sg.
	krok [krɔk] ‘step’	krocz-ek [krɔtʂɛk] dim.
	drog-a [drɔga] ‘way’	dróż-ek [druʐɛk] gen.pl.dim.
	grzech [gʐɛx] ‘sin’	grzesz-ek [gʐɛʂɛk] dim.

Polish palatalization has been used to argue for specific models of rule-based theories (Rubach, 1984) or representational theories (Gussmann, 1992; Rubach, 2007). Some recent analyses place emphasis on the morphological conditioning of the alternations (Gussmann, 2007, Czaplicki, 2013, 2014a, 2018). Straightforward motivation for the latter approach comes from the behavior of velars in (7c), where it is observed that [k] has three different alternants before [ɛ]: [c], [ts] and [tʂ]. The data in (7) are representative of palatalization as a process of phonologization of coarticulatory effects between adjacent consonants and front vowels. These alternations are arguably phonologically natural from the synchronic perspective as well.[5]

Let us turn to alternations that do not easily conform to the naturalness requirement. The data in (8) show the effects of the diminutive suffix *-ek* on the base-final consonant.

(8)	a.	świat [ɕfjat] ‘world’	świat-ek [ɕfjatɛk]
		spod-u [sput] ‘bottom’ gen.sg.	spod-ek [spɔdɛk]
		win-o [vʲin-ɔ] ‘wine’	win-ek [vʲinɛk] gen.pl.
		nos [nɔs] ‘nose’	nos-ek [nɔsɛk]
		woz-u [vɔzu] ‘cart’ gen.sg.	wóz-ek [vuzɛk]
		dół [duw] ‘hole’	doł-ek [dɔwɛk]
		wór [vur] ‘sack’	wor-ek [vɔrɛk]
	b.	krok [krɔk] ‘step’	krocz-ek [krɔtʂɛk]
		prog-u [prɔgu] ‘doorstep’ gen.sg.	proż-ek [prɔʐɛk]
		duch [dux] ‘ghost’	dusz-ek [duʂɛk] gen.pl.
	c.	gołębi-a [gɔwɛmbja] ‘pigeon’ gen.sg.	gołąb-ek [gɔwɔmbɛk]
		liść [lʲiɕtɕ] ‘leaf’	list-ek [lʲistɛk]
		kość [kɔɕtɕ] ‘bone’	kost-ek [kɔstɛk] gen. pl.
		kmieć [kmjɛtɕ] ‘peasant’	kmiot-ek [kmjɔtɛk]
		pacierz-a [patɕɛʒa] ‘prayer’ gen.sg.	pacior-ek [patɕɔrɛk]
		niedźwiedzi-a [ɲɛdʑvjɛdʑa] ‘bear’ gen.sg.	niedźwiad-ek [ɲɛdʑvjadɛk]
		jeleń [jɛlɛɲ] ‘stag’	jelon-ek [jɛlɔnɛk]
		dzień [dʑɛɲ] ‘day’	dzion-ek [dʑɔnɛk]
		gęś [gɛ̃j̃ɕ] ‘goose’	gąs-ek [gɔw̃sɛk] gen. pl.
		ćwierć [tɕfjɛrtɕ] ‘quarter’	ćwiart-ek [tɕfjartɛk] gen. pl.

[5] However, retroflexes in (7c) are problematic as outputs of palatalization because retroflexion is incompatible with raising and fronting the tongue body for front vowels (Hamann, 2002). This is an example of opacity that results from a succession of historical changes which were phonetically motivated at the time of happening but the final outcome no longer shows phonetic motivation.

While this *e*-initial suffix leaves coronals unaffected, (8a), velars appear as their retroflex counterparts before it, as can be seen in (8b). What is especially interesting, as visible in (8c), the concatenation of the diminutive suffix results in the depalatalization of the preceding palatalized labials and coronals. It appears that [ɛ], a front vowel, is responsible for the depalatalization of coronals and labials.

The second palatalization-related regularity whose effects are problematic if phonological naturalness is a bias in synchronic grammars is associated with *-arz*, a suffix used to form agent nouns. In each case in (9), we look at two derivatives formed with the suffix *-arz* [-aʂ]: in (8a) palatalization fails to apply, while (9b) shows palatalizing effects (mutations) in exactly the same context (data from Gussmann, 2007).

(9)	a.	karczm-a [kartʂma] 'tavern'	karczm-arz [kartʂmaʂ] 'tavern keeper'
	b.	reklam-a [rɛklama] 'advertisment'	reklami-arz [rɛklamjaʂ] 'advertizer'
	a.	gospod-a [gɔspɔda] 'inn'	gospod-arz [gɔspɔdaʂ] 'inn keeper'
	b.	lod-y [lɔdɨ] 'ice cream'	lodzi-arz [lɔdʑaʂ] 'ice-cream vendor'
	a.	młyn [mwɨn] 'mill'	młyn-arz [mwɨnaʂ] 'miller'
	b.	komin [kɔmʲin] 'chimney'	komini-arz [kɔmʲiɲaʂ] 'chimney-sweep'
	a.	moc [mɔts] 'might'	moc-arz [mɔtsaʂ] 'mighty ruler'
	b.	owc-a [ɔftsa] 'sheep'	owcz-arz [ɔftʂaʂ] 'sheep farmer'
	a.	druk [druk] 'printing'	druk-arz [drukaʂ] 'printer'
	b.	mlek-o [mlɛkɔ] 'milk'	mlecz-arz [mlɛtʂaʂ] 'milkman'

The data in (9) present a somewhat simplified picture of the distribution of the alternating vs. non-alternating variants for each base-final consonant before *-arz*. Although both patterns are attested, one of them is more frequent than the other and this pattern is used in the formation of recent and novel words. As an illustration, in (10) I provide derivatives with base-final [k] and [n], representing velars and coronals, respectively. The table shows the number of words for each base-final consonant, where *-arz* is either responsible for a mutation or not (data based on Bańko et al., 2003).

(10) Segmental alternations before *-arz*

		No alternations		Alternations
a.	[k ∼ k]	80 words dru[k] 'print' – dru[k]-arz 'printer' recent formations: kaja[k]-arz 'kayaker' rol[k]-arz 'roller skater' kafej[k]-arz 'café owner' stiu[k]-arz 'plasterer'	[k ∼ tʂ]	6 words mle[k]-o 'milk' – mle[tʂ]-arz 'milkman' recent formations: none
b.	[n ∼ n]	5 words mły[n] 'mill' – mły[n]-arz 'miller' recent formations: none	[n ∼ ɲ]	48 words komi[n] 'chimney' – komi[ɲ]-arz 'chimney-sweep' recent formations: ki[ɲ]-arz 'cinema owner' kanty[ɲ]-arz 'canteen owner' balo[ɲ]-arz 'balloon pilot' ochro[ɲ]-arz 'security guard'

While the nasal in (10b) shows a significantly higher incidence of the palatalized variant than a non-palatalized one before *-arz*, the velar stop in (10a) predominately appears unchanged before the suffix. A regularity that emerges from (10) is that, while both patterns are attested in the lexicon for [k] and [n], only the more frequent one is readily extended to recent formations. The less common one of the two is restricted to well-established words. On the basis of this, it can be concluded that velars predominately appear in their non-mutated variants before *-arz*, while coronals tend to appear as palatalized.[6] There are three problems that this observation poses for an analysis that relies on phonological naturalness. First, palatalization before back vowels does not have a phonetic motivation. Second, a class of consonants behaves differently than another class in the same phonological context (i.e. coronals vs. velars).

The third problem becomes evident when we compare the distribution of palatalization effects before *-arz* with that before the suffix *-ek*, as exemplified in (11) (Czaplicki, 2014b).

[6] Not all base-final consonants show a sufficient number of derivatives in *-arz* to risk a statement about the productivity of one of the two competing patterns. Some consonants appear exclusively as their palatalized counterparts before *-arz*, e.g. [t] and [w] appear as [tɕ] and [l] respectively (Czaplicki, 2014a).

(11)	base-final cons.	*-arz*	*-ek*
	[…n]	[…ɲ-aʂ]	[…n-ɛk]
	[…k]	[…k-aʂ]	[…tʂ-ɛk]

Coronals appear as their mutated (palatalized) counterparts and velars as their non-mutated counterparts before *-arz*. Exactly the reverse pattern can be observed before *-ek*, i.e. velars appear as their mutated counterparts while coronals remain unaffected (in fact, there is depalatalization in this case). Phonological naturalness plays no role here: a back vowel is responsible for palatalization and a front vowel for depalatalization. It is difficult to reconcile these alternation patterns with approaches that incorporate naturalness in synchronic grammars. Instead, the distribution of mutations appears to be in large part governed by individual morphemes.

The pattern *-arz* in (10b) is important for yet another reason. It exemplifies a replacement of a natural pattern in well-established words (a non-palatal coronal appears before a back vowel, e.g. *mły*[n]*-arz*) by an unnatural pattern in novel words (a palatal coronal appears before a back vowel, e.g. *ochro*[ɲ]*-arz*). As a result, the unnatural pattern emerges as productive. Given a choice between a natural and an unnatural pattern in the same morphological context, the learner chooses the unnatural pattern. This is evidence that unnatural patterns, in addition to being learnable, are not harder to learn than their natural counterparts. A related finding is that the productivity of a pattern does not depend on its naturalness.

So far, the search for phonologically unnatural palatalization processes has revealed instances of palatalization before back vowels and depalatalization before front vowels. The last hypothetical case in (12) pertains to instances of palatalization before non-palatal consonants. Such cases can easily be found in Polish (Gussmann, 2007, 127, 149).

(12)	Palatalization before non-palatal consonants	
	skał-a [skawa] ‘rock’	skal-n-y [skalnɨ] adj.
	głos [gwɔs] ‘voice’	głoɕ-n-y [gwɔɕnɨ] ‘loud’
	groz-a [grɔza] ‘awe’	groź-n-y [grɔʑnɨ] ‘threatening’
	rok [rɔk] ‘year’	rocz-n-y [rɔtʂnɨ] ‘annual’
	śnieg-u [ɕɲɛgu] ‘snow’ gen. sg.	śnież-n-y [ɕɲɛʐnɨ] ‘snowy’
	strach [strax] ‘fear’	strasz-n-y [straʂnɨ] ‘awful’

Obviously, phonetic coarticulation has no role to play in motivating the alternations in (12). The mutation of the relevant consonant cannot be linked to the immediately following consonant in any plausible phonetic way.[7] It follows that phonological naturalness is irrelevant for these patterns. This exhausts the range of contexts where approaches that appeal to phonological naturalness would *not* predict palatalization to be possible. Yet, such patterns of unnatural palatalization are attested and productive in Polish. It appears that back vowels and non-palatal consonants trigger various types of palatalization, while front vowels are responsible for depalatalization. However, the mere attestation of unnatural patterns in a language says little about how common such patterns are in the language. This issue is dealt with in the following section, where we look at quantitative data related to consonant mutations.

4.2. Measuring the phonological naturalness of consonant mutations

This section has two goals: it aims to measure the rate of naturalness of consonant mutations and assess the relative importance of naturalness for this pattern. Measuring the rate of natural to unnatural patterns in the data provides a useful representation of linguistic input that a language learner is exposed to. However, the rate of naturalness tells us nothing about the role of other potential factors in predicting consonant mutations. In order to place naturalness in the appropriate context, I assess its importance in relation to other factors, both phonological and morphological. Two outcomes of the analysis can be envisaged: (i) it is found that unnatural patterns are significantly less common than natural patterns, and (ii) unnatural patterns turn out to be as common as natural patterns. As for the assessment of the relative importance of naturalness, the possible outcomes include (i) discovering that naturalness reliably predicts consonant alternations, and (ii) finding that naturalness is a poor predictor of consonant alternations in relation to other factors. If the former outcome for both analyses is true, we can assume that the mechanisms responsible for learning and generating unnatural patterns are not as regular and active as those dedicated to natural patterns. What is more, unnatural patterns might not require operations (rules or constraints) similar to those required for natural patterns; the mutations could be analyzed as exceptional and stored in the lexicon as such (cf. Kiparsky, 2008). If, on the other hand, the latter outcome turns out to be true, the operations responsible for handling unnatural patterns must be encoded in the grammar in the same way as the operations generating natural patterns. In addition, the discussion touches on the relevance of the already mentioned straitjacket effects. A stance that assumes an active bias of grammar against unnatural patterns has problems explaining the persistence of such patterns. Being more difficult to acquire, unnatural patterns should be gradually eliminated by successive generations of learners.

[7] Palatalization is not fully predictable in this context, as it is not found in structurally similar words, such as *mięs-o* [mjɛw̃sɔ] ‘meat’ *mięs-n-y* [mjɛw̃snɨ] ‘meaty’ and *żelaz-o* [ʐɛlazɔ] ‘iron’ *żelaz-n-y* [ʐɛlaznɨ] adj. (Gussmann, 2007, 151).

Polish consonant mutations serve as a testing ground for measuring the rate of naturalness that a language learner is exposed to. Consonant-vowel or consonant–consonant configurations that meet the articulatory requirements of palatalization (palatal articulation before a front vowel or a palatal consonant, non-palatal articulation before a back vowel or a non-palatal consonant) are classified as natural. An output that does not meet these requirements is considered unnatural. Retroflexes [ʂ ʐ tʂ dʐ] are classified as non-palatal, in accordance with phonetic evidence showing that retroflexion is incompatible with palatalization (Hamann, 2002) and evidence from expressive morphology indicating that retroflexes, in contrast to alveolopalatals, are not used to signal smallness and affection in diminutives and hypocoristics (Czaplicki, 2016b).[8]

I examine the outputs of the concatenation of mutation-triggering vowel- and consonant-initial suffixes. The effects of 27 suffixes have been analyzed: 9 of them beginning with *i* [i] (or *y* [ɨ]), 7 with *e* [ɛ], 8 with *a* [a] and 3 with a consonant. Suffixes beginning with other vowels (i.e. /ɔ/ and /u/) have not been included because they do not trigger mutations (perhaps with the exception of *-och* /ɔx/, which does trigger mutations, e.g. *tłust-y* [twustɨ] 'fat' *tłuści-och* [twuɕtɕɔx] 'fat person', but is not productive). Only mutation-triggering suffixes have been chosen because the main purpose of this analysis is to identify the types of consonant mutations that a language learner is exposed to. The suffixes have been selected on the basis of Gussmann (2007) and Grzegorczykowa and Puzynina (1999) and are listed in Appendix A. 32 base-final consonants have been considered.

(13) Base-final consonants
labials: /p b m f v w/
palatalized labials: /pʲ bʲ mʲ fʲ vʲ/[9]
coronals: t d s z n ts dz r l ʂ ʐ tʂ dʐ/
palatalized coronals: /ɕ ʑ tɕ dʑ ɲ/
velars: /k g x/

A dictionary search has been performed and *all and only* the attested effects have been investigated taking into account a particular base-final consonant in the context of a particular suffix, which gives the total number 604. This decision is motivated by several factors: (i) not all base-final consonants appear before a given suffix, (ii) most suffixes exhibit inconsistent effects on the preceding consonant (e.g. one suffix can lead to palatalization for some consonants and depalatalization for others), (iii) several patterns of behavior are attested in a single morphophonological context and (iv) mutations are suffix specific, (cf. Gussmann, 2007; Czaplicki, 2013, 2014a, 2018).[10]

Out of the 604 mutations 396 have been classified as natural (65.6%) and 208 (34.4%) as unnatural. These numbers, however, offer a simplified account of the facts. We need to take into consideration various aspects of the suffix-initial segments (triggers) and the base-final consonants (targets) that might play a role in predicting the naturalness of the outputs. For the purposes of the following analysis, the dependent variable is palatality of the target, that is, of the base-final consonant in the corresponding affixed form. The main aim is to determine the extent to which various phonological and morphological factors predict palatality of the target.

It is important to make a distinction between the triggers and targets of mutations in $C_{base} + V_{suffix}$ or $C_{base} + C_{suffix}$ sequences. The central hypothesis is that the palatality of the target depends on the following trigger – the suffix-initial segment, that is, V_{suffix} or C_{suffix}. However, we will also examine the role of the target, that is the quality of the base-final consonant, C_{base}. We will test the hypothesis that the palatality of the target consonant depends on the consonant in the base (e.g. [t s b]) or, more generally, on the place of articulation of the base-final consonant (labial, coronal, dorsal). The independent variables used in the present analysis, and the levels coded for under each variable, are given in (14).

(14) *Suffix*: suffix used after the target: *-em* instr.sg., *-ek* dim., *-arz* agent nouns, etc. (27 levels)
Suffix segment: suffix-initial segment: [i ɨ ɛ a C Cʲ] (6 levels)
Suffix [±back]: frontness (palatality) vs. backness (non-palatality) of the suffix-initial vowel (consonant): [-back] vs. [+back] (2 levels)
Consonant: base-final consonant: [p pʲ b bʲ m mʲ f fʲ v vʲ …] (32 levels)
Place of consonant: place of articulation of the base-final consonant: labial, coronal, dorsal (3 levels)

Some of the variables in (14) rely more on phonological information and others depend to a larger extent on morphological information. For example, the variable *Suffix* is morphologically defined, in the sense that different suffixes with the same initial vowel are coded as different levels. The variable *Suffix [±back]*, on the other hand, is defined phonologically, as its levels

[8] Palatal consonants are often employed in the so-called expressive palatalization. This is an instance of iconicity (sound symbolism) in language (Ohala, 1994).

[9] The contrast between palatalized and non-palatalized labials is neutralized word finally but shows up prevocalically, e.g. *jastrząb* [jastʂɔmp] 'hawk' – *jastrzębi-a* [jastʂɛmbja] gen.sg. vs. *ząb* [zɔmp] 'tooth' – *zęb-a* [zɛmba] gen.sg.

[10] A reviewer points out that the current analysis is based on word types (a dictionary search) and that looking at tokens (frequency-weighted) might give different results. While this is an interesting topic for future research, there is some evidence that token frequency cannot be the only factor involved. For instance, diminutive formation using *-ek*, which, according to Grzegorczykowa and Puzynina (1999, 425), is among the most productive word-formation patterns in Polish, displays a 2:24 ratio of natural to unnatural patterns.

make reference to the feature [±back]. *Suffix segment* is also phonologically based, however, instead of referencing one feature, it makes use of the inventory of contrastive segments in Polish. Similarly, the variable *Place of consonant* is based on one phonological dimension (place features), while the variable *Consonant* refers to specific consonants that are contrastive in Polish. We will try to determine to what extent palatality is dependent on morphological and phonological factors, and, considering the latter, whether phonological features play a role, or, rather, individual segments irrespective of their [±back] specification are better predictors of the palatality of the target.

Let us consider the relationship between palatality and the properties of the trigger, that is, the suffix-initial segment. Fig. 1 shows the rates of palatal consonants in the output before a particular suffix-initial vowel ([i ɨ ɛ a]) and non-palatal (c) and palatal (c') consonant (variable *Suffix segment*).[11]

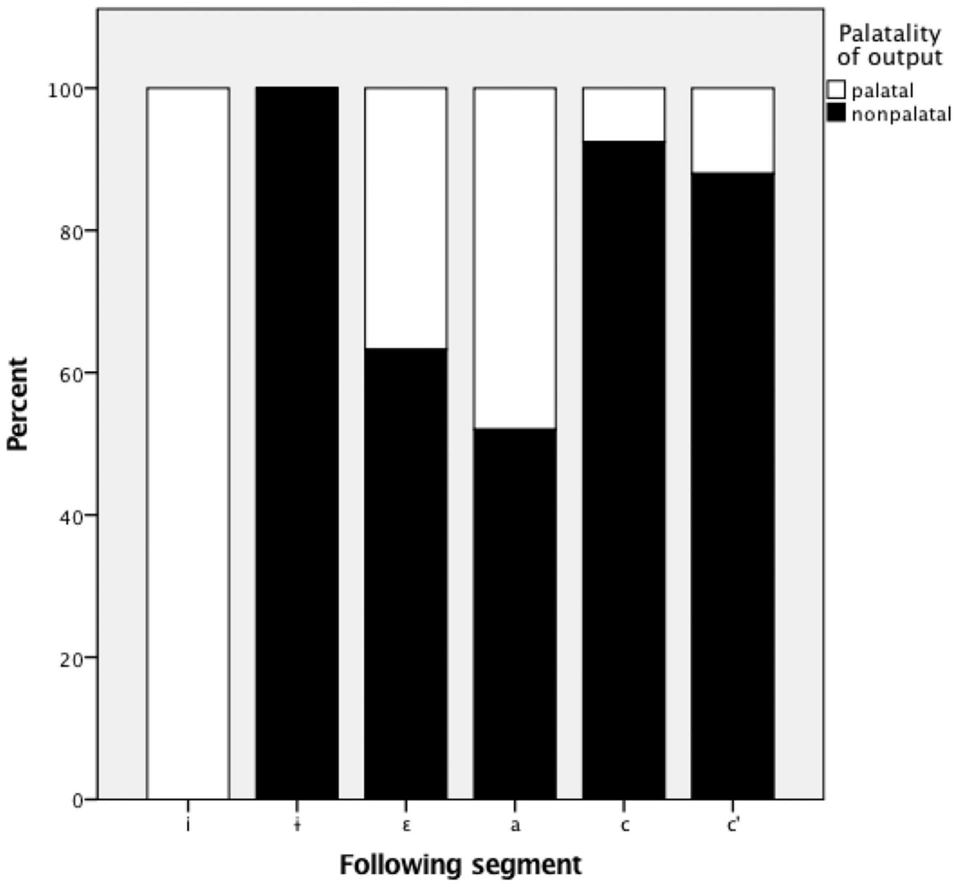

Fig. 1. Rates of palatal/nonpalatal outputs according to suffix-initial segment.

The context of vowel [i] results exclusively in palatal outputs, while the context of [ɨ] in non-palatal outputs. This is due to the complementary distribution of the vowels after the base-final consonant: [i] appears after palatal consonants, while [ɨ] after non-palatal consonants, including retroflexes, e.g. *flet* [flɛt] 'flute' – *flec-ist-a* [flɛtɕista] 'flute-player' and *szantaż* [ʂantaʂ] 'blackmail' – *szantaż-yst-a* [ʂantaʐɨsta] 'blackmailer'. Importantly, suffix-initial vowels [i] and [ɨ] result exclusively in natural patterns: palatals before front [i] and non-palatals before non-front [ɨ].

For the two remaining vowels, unnatural patterns constitute a significant portion of the data. In the context of non-front [a] the number of preceding palatals approximates the number of preceding non-palatals, the latter engendering natural patterns. As regards the context of [ɛ], unnatural patterns outnumber natural patterns: there are more non-palatals than palatals before front [ɛ]. Before suffix-initial consonants non-palatals appear in approximately 90% cases, irrespective of the palatality of the consonants (i.e. c and c'). The results suggest that front vowels do not function as a class and that the tools (rules, constraints or schemas) dedicated to vowels [i] and [ɨ] should be distinct from those used for the vowel [ɛ] (we come back to this issue in Section 5.4). However, the low rates of naturalness before [ɛ] and [a] (i.e. non-palatal consonants before [ɛ]

[11] For convenience, the figures show percentages. The exact values underlying these percentages are provided in Appendix B.

and palatal consonants before [a]) do not follow from theories that represent mutations in terms of featural agreement in CV sequences. It rather appears that the context of [ɛ] brings about a *dispreference* for natural patterns, while before [a] there is no preference either way.

Another aspect that is investigated is the relationship between palatality and the suffix (variable *Suffix*). Fig. 2 suggests that the rate of palatal and non-palatal outputs might be to a large extent suffix specific. For example, the addition of different [ɛ]-initial suffixes yields different effects: e1 triggers mostly palatal outputs, while e3 produces predominately non-palatal outputs. Note, however, that none of the suffixes gives rise to exclusively palatal or exclusively non-palatal outputs.[12]

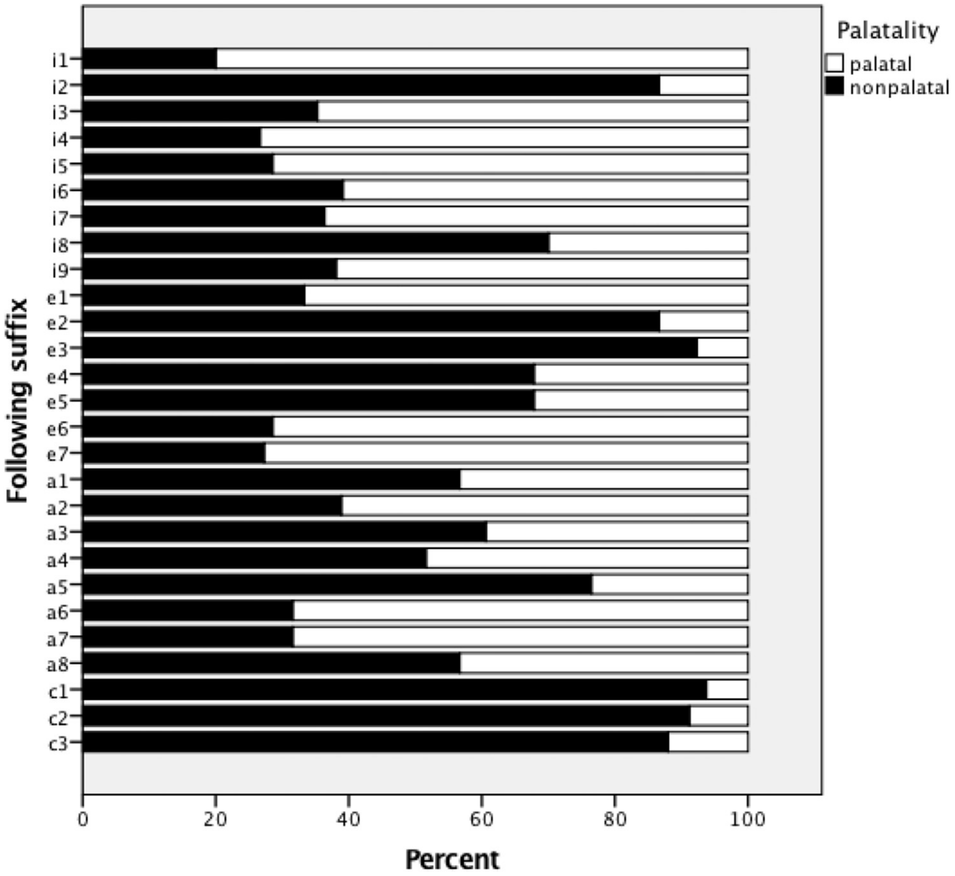

Fig. 2. Rates of palatal/non-palatal outputs according to suffix.

A phonological account based on naturalness predicts that front vowels (i.e. /i ɛ/) should occur with palatal consonants, while back vowels (i.e. /a/) with non-palatal consonants. Put differently, palatal consonants are natural before front vowels, while non-palatal consonants are natural before back vowels. Suffix-initial consonants should have a parallel effect on the preceding consonant: the resulting consonant clusters should agree in palatality. Fig. 3 examines whether the palatality of the target consonant is associated with the frontness/palatality of the suffix-initial segment. Palatal outputs appear in approximately 60% of cases before front/palatal segments and in 30% of cases before non-front/non-palatal segments.

[12] Arguably, another approach would be to differentiate the suffixes that show divergent behavior by referring to a “deeper” level of representation. For example, the suffix *-ek* [ɛk] (e3), which appears in 80% of the cases with non-palatal consonants, could be represented as /ɤk/, i.e. with a back unrounded vowel. In this analysis, vowel /ɤ/ could be held responsible for lack of palatalization (or for depalatalization) and then be fronted to /ɛ/. Similarly, the suffix *-ast-y* [astɨ] (a7), which appears in 68% of the cases after palatal consonants (e.g. *pas* [pas] ’stripe’ – *pasi-ast-y* [paɕastɨ] ’striped’), could be represented as /æstɨ/ or /jastɨ/. Such an approach is undesirable for several reasons. First, the representations would have to be excessively abstract. Second, *i*/*ɨ*-initial suffixes do not require comparable abstract representations, as the patterns before them are exclusively phonetically transparent. Third, even if such abstract representations were accepted, some of the patterns would still remain unnatural, as the rates of (non-)palatality never reach 100% in Fig. 2.

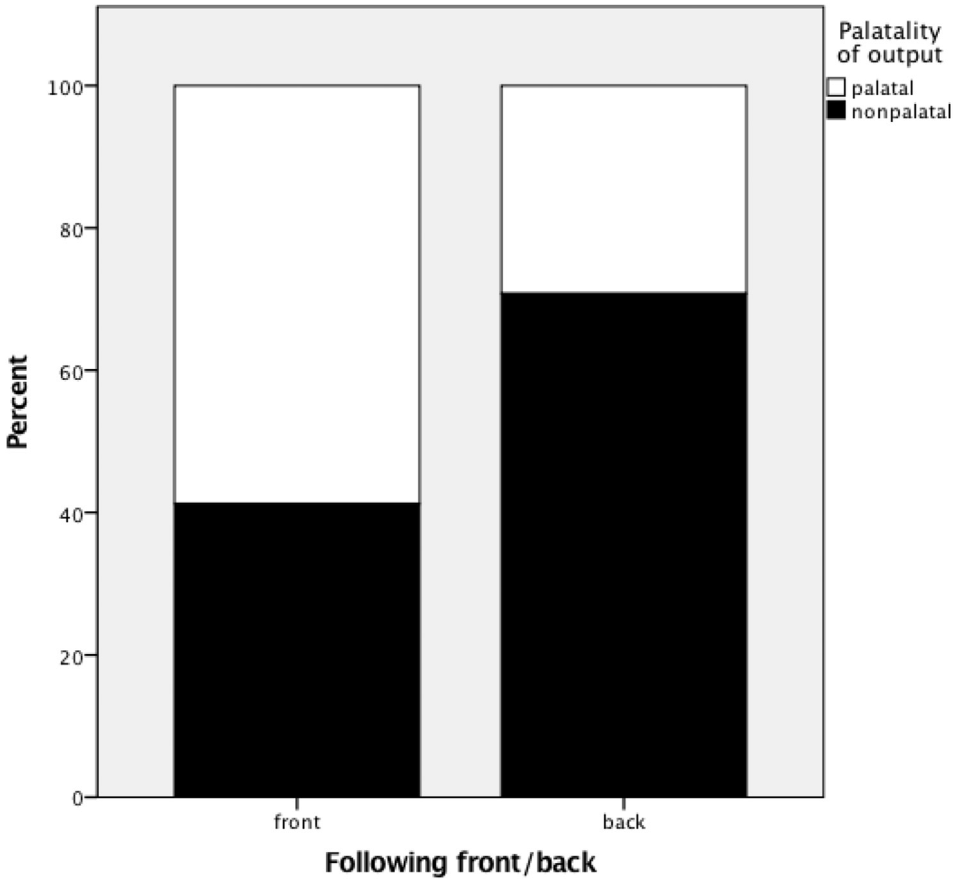

Fig. 3. Rates of palatal/non-palatal outputs according to frontness (palatality) of the following vowel (consonant).

As regards the role of targets, Fig. 4 shows the rates of palatal and non-palatal outputs for each base-final consonant. There are large differences among consonants. On the one hand, /r ts/ and retroflexes /ʐ tʂ dʐ/ always result in non-palatal outputs before a suffix, on the other, /ɕ ʑ tɕ dʑ ɲ/ and palatalized labials predominantly appear as palatals (however, only /ʑ/ among them exhibits categorical behavior). Many of the remaining consonants do not show a clear tendency one way or the other, e.g. /t d l/.

In order to find out whether there is a significant association between palatality and various aspects of the triggers and targets, a series of random forests using R's party package (Hothorn et al., 2006) were run on the data with palatality as the dependent variable and the independent variables (predictors) as given in (14).[13] Random forests were employed because they are well equipped to deal with a large number of predictors in the same model. In addition, random forests can be used with highly collinear predictors. The aim was to assess the importance of each of the factors for predicting the palatality of output consonants.

In the dotplot in Fig. 5 the predictors have been arranged from the most to the least important. It appears that *Suffix segment* and *Base consonant (Consonant)* contribute the most as predictors of palatality. *Suffix* is also important but less so than the previous two factors. The remaining two factors, *Place of consonant (Place)* and *Suffix [±back] (SuffixBack)*, are poor predictors of palatality. These results suggest that the palatality of output consonants overwhelmingly depends on the specific suffix-initial vowel (or consonant), as well as on the base-final consonant. Both these factors make reference to individual segments in Polish (phonemic distinctions), indicating that palatality is segment specific, including suffix-initial and base-final segments. Morphological factors also contribute: palatality significantly depends on the following suffix. Crucially, both factors encoded by single phonological dimensions, that is, *Suffix* [±back] and *Place of articulation*, contribute relatively little and hence cannot be used as reliable predictors of palatality.

[13] The random forest approach is an ensemble learning technique. A number of decision trees are created. Every observation is fed into every decision tree. The most common outcome for each observation is used as the final output. A new observation is fed into all the trees and a majority vote for each classification model is taken. The forest chooses the classification having the most votes.

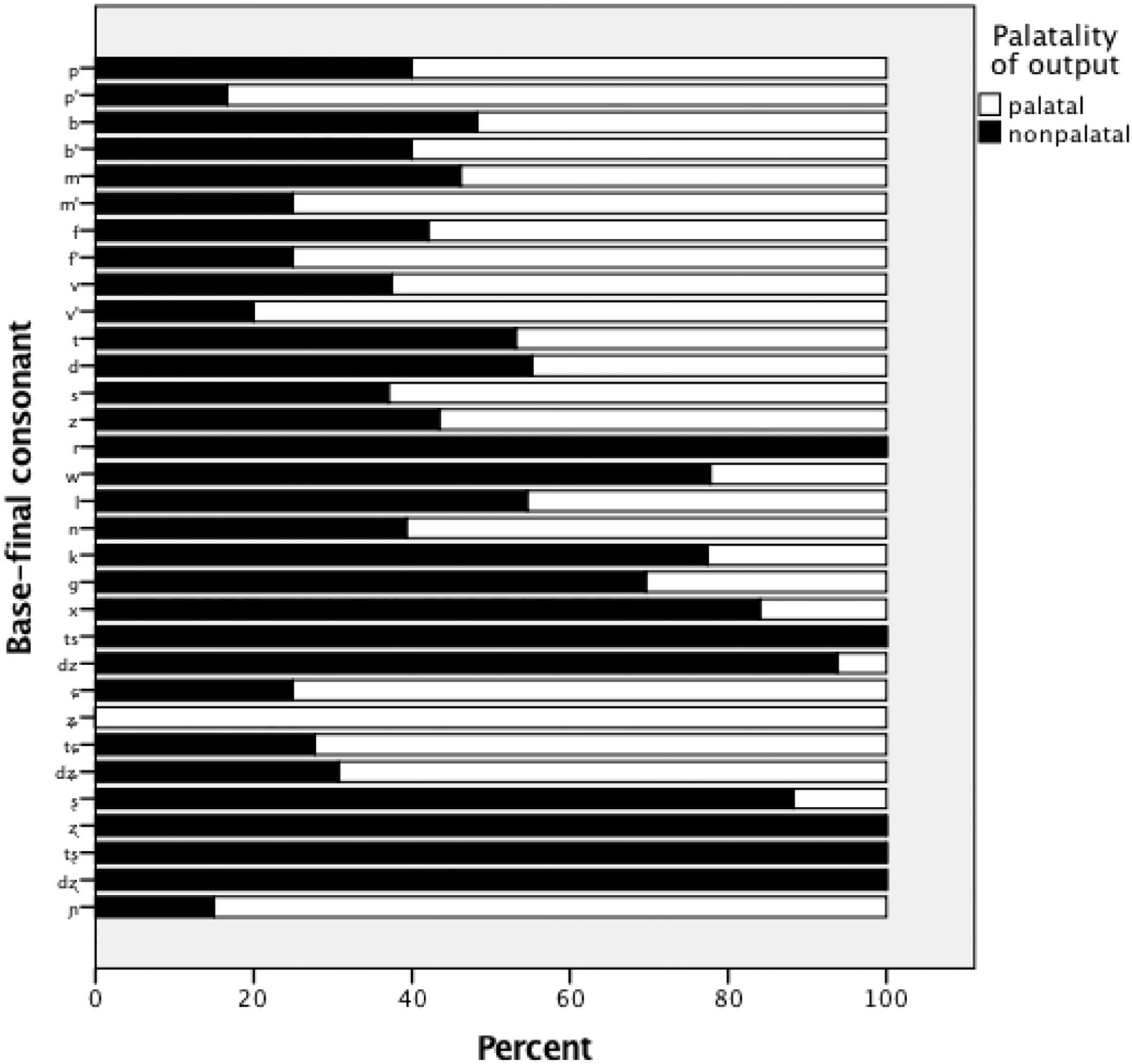

Fig. 4. Rates of palatal/non-palatal outputs according to base-final consonant.

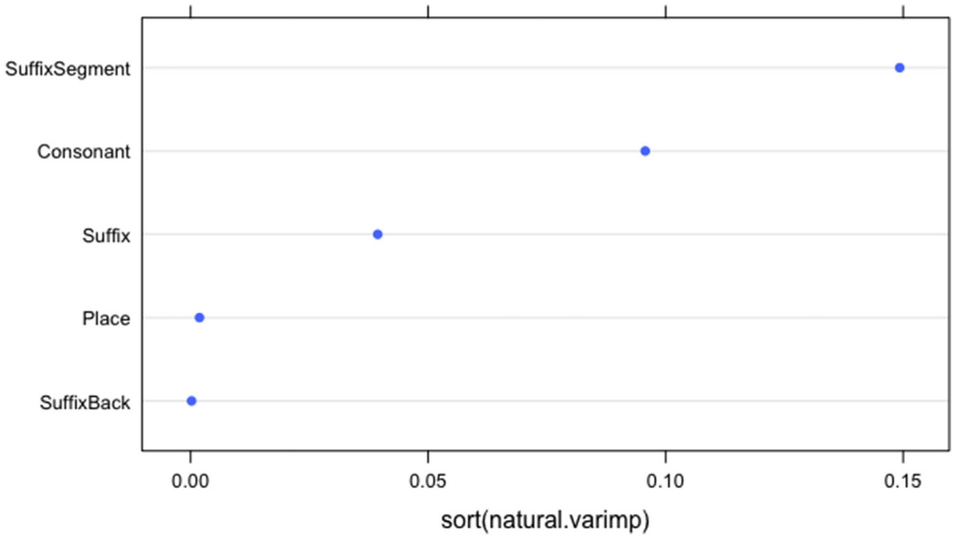

Fig. 5. Variable importance of factors from random forests for predicting palatality of output consonants.

The upshot of the analysis is that palatality depends the most on the following suffix-initial segment. The current analysis has failed to show a connection between the palatality of the output and the backness (palatality) of the following vowel (consonant). We conclude that phonological naturalness, defined as agreement in the feature [±back] in CV (and CC) sequences, is not relevant for Polish consonant mutations. The outcome of mutations is predictable from the specific segment that follows, the specific suffix and the specific consonant undergoing a mutation.

This discussion has also revealed some interesting facts about vowels. Front vowels do not function as a class: while [i] appears exclusively after palatal consonants, [ɛ] appears most often after non-palatal consonants (>60%). The back vowel [a] appears equally often after palatal and non-palatal consonants. The vowel [ɨ] appears exclusively after non-palatal consonants. It turns out that naturalness does not play a role in conditioning consonant mutations before [ɛ] and [a] but it does in conditioning consonant mutations before [i] and [ɨ].[14]

Finally, this discussion has shown that the cover-term “palatalization” is inappropriate and should be replaced with “morphologically conditioned consonant mutations” for the Polish data. The term “palatalization” does not reflect the conditioning and diversity of the discussed regularities.

4.3. *Progressive devoicing*

As already mentioned, there is strong evidence that certain positions in a string of segments are beneficial for the maintenance of voice distinctions. Voicing contrast tends to be maintained before vowels and is often lost in the prepausal and preconsonantal positions. A plausible explanation for this patterning can be found in phonetics. The perceptual salience of many of the cues for the perception of voicing (closure voicing, closure duration, duration of preceding vowel, F_0 and F_1 values in preceding and following vowels, VOT values, burst duration and amplitude) is diminished in these positions (Yu, 2014, 300). In (15), I repeat Steriade’s (1999) universal perceptibility scale for voicing. This perceptibility scale provides the basis for the ranking of constraints that ban voicing contrast in specific positions, shown in (16).

(15) Scale of obstruent voicing perceptibility according to context (Steriade, 1999, 11)
V__[+son] > V__# > V__[-son] > {[-son]__[-son], [-son]__#, #__[-son]}

(16) Ranking of constraints based on the perceptibility scale (Steriade, 1999, 11)
*αvoice/[-son]__[-son], [-son]__#, #__[-son] >> *αvoice/V__[-son] >> *αvoice/V__# >> *αvoice/V__[+son]

The constraints in (16) are part of a synchronic grammar and offer clear predictions with respect to the typology of voicing contrast. Voicing contrast is licensed in positions where many cues are potentially available (between sonorants). This is accomplished by ranking low the relevant *αvoice constraint (*αvoice/V__[+son]). In positions with relatively few cues voicing contrast is endangered because the relevant *αvoice constraints are ranked high. The ranking of these constraints with respect to each other is universal because acoustic and perception factors are universal.

There is plenty of evidence that the universal constraints on perception in (16) play a role in the maintenance and neutralization of voicing contrast in Polish (data drawn from Gussmann, 2007, 289–292).

(17)	a.	tam [tam] ‘there’	dam [dam] ‘I will give’
	b.	chleb-a [xlɛba] ‘bread’ gen.sg.	chleb [xlɛp] nom.sg.
		rad-a [rada] ‘advice’ nom.sg.	rad [rat] gen.pl.
	c.	kto [ktɔ] ‘who’	gdy [gdɨ] ‘when’
	d.	groz-i-ć [grɔʑitɕ] ‘threaten’	groź-b-a [grɔʑba] ‘threat’
		rzeźb-i-ć [ʐɛʑbitɕ] ‘sculpture’ verb	rzeźb-a [ʐɛʑba] ‘sculpture’ noun
	e.	pros-i-ć [prɔɕitɕ] ‘ask’	proś-b-a [prɔʑba] ‘request’ noun
		licz-y-ć [litʂɨtɕ] ‘count’	licz-b-a [lidʐba] ‘number’
	f.	młot-a [mwɔta] ‘hammer’ gen.sg.	młot-k-a [mwɔtka] dim. gen.sg.
		łap-a [wapa] ‘paw’	łap-k-a [wapka] dim.
	g.	żab-a [ʐaba] ‘frog’	żab-k-a [ʐapka] dim.
		łyżek [wɨʐɛk] ‘spoon’ gen.pl.	łyżk-a [wɨʂka] dim.
	h.	móżdż-ek [muʐdʐɛk] ‘brain’ dim.	móżdż-k-u [muʂtʂku] gen.sg.
		gwiazd-a [gvjazda] ‘star’	gwiazd-k-a [gvjastka] dim.

The items in (17a) show that voicing contrast is maintained before vowels. Final devoicing is illustrated in (17b). The items in (17c–h) demonstrate that obstruent clusters agree in voicing. The last obstruent of the cluster maintains its voice specification because of the context of the following vowel. The preceding obstruent (or obstruents) is in preconsonantal

[14] A reviewer suggests that Polish might use the tense/lax distinction in order to put vowels [i] and [ɛ] into separate classes. On this view, the tense/lax dimension would have to be used for palatal/non-palatal consonants. While this proposal deserves a closer look, it encounters similar problems: around 40% of outputs before [ɛ] and 50% before [a] remain unaccounted for (i.e. unnatural).

position, which is not hospitable to contrast maintenance. The items in (17c) show static generalizations about agreement in obstruent clusters in word-initial clusters (i.e. [gtɔ] and [kdɨ] are impossible). The remaining data display dynamic contexts. The changes sampled in (17c–h) fall under the category of regressive voice assimilation. In a phonetically based phonological analysis of the data in (17), prevocalic position is protected due to the presence of multiple cues to voicing. The constraint that bans contrast in voicing in this position is ranked below the constraint Preserve[voice], which enforces faithfulness to input voice specification. The *αvoice constraints regulating contrast maintenance in other positions (i.e. before obstruents and word-finally) are ranked above Preserve[voice], which entails contrast neutralization in these positions.

(18) Ranking of *αvoice constraints for Polish
*αvoice/#__[-son] >> *αvoice/V__[-son] >> *αvoice/V__# >> Preserve[voice] >> *αvoice/V__[+son]

However, there is a productive process related to voicing contrast neutralization that is problematic from the point of view of such a phonetically based approach. This process is referred to as progressive devoicing in the literature (data from Gussmann, 2007, 307 and Rubach, 1996).

(19)	a.	chorągiew-ek [xɔrɔŋɟɛvɛk] ‘banner’ dim. gen.pl.	chorągw-i [xɔrɔŋgvi] gen.sg.
		łyżew [wɨʐɛf] ‘skate’ gen.pl.	łyżw-y [wɨʐvɨ] nom.pl.
	b.	szew-ek [ʂɛvɛk] ‘seam’ dim.	szw-y [ʂfɨ] nom.pl.
		marchew-nik [marxɛvɲik] ‘carrot leaves’	marchw-i [marxfi] ‘carrot’ gen.sg.
		bitew-n-y [bʲitɛvnɨ] ‘battle’ adj.	bitw-a [bʲitfa] ‘battle’
	c.	gr-a [gra] ‘game’	grz-e [gʐɛ] dat.sg.
		dobr-y [dɔbrɨ] ‘good’	dobrz-e [dɔbʐɛ] ‘well’
	d.	kr-a [kra] ‘ice floe’	krz-e [kʂɛ] dat.sg.
		łotr-a [wɔtra] ‘rascal’ gen.sg.	łotrz-yk [wɔtʂɨk] dim.
		do-cier-a-ć [dɔtɕɛratɕ] ‘reach’	do-trz-e [dɔtʂɛ] ‘(s)he will reach’
		krew-n-y [krɛvnɨ] ‘relative’	krw-i [krfʲi] ‘blood’ gen.sg.

Just like in the data in (17), the items in (19) show that obstruent clusters agree in voicing. This is also visible in (19b) and (19d), where /v/ and /ʐ/ are devoiced to /f/ and /ʂ/, respectively, in prevocalic position.[15]

Progressive devoicing applies in borrowings, as demonstrated in (20). The items in (20a) and (20b) show progressive devoicing of /v/. The item in (20a) presents an alternation, while in the items in (20b) progressive devoicing of /v/ can be deduced from the spelling. Words often enter a language in their orthographic forms and Polish speakers consistently pronounce the spelled *w* in prevocalic position as [f] in the words in (20b). What is more, some of the words are pronounced with [v] in the donor language, e.g. the word for ‘Moscow’ in Russian. The items in (20b) indicate that the process is not morphologically restricted.[16] The items in (20c) illustrate the productivity of progressive devoicing applying to /ʐ/ in borrowings and proper names. In sum, the items in (20) show that progressive devoicing is as productive and regular as regressive voice assimilation illustrated in (17), the only restriction is that it affects [v] and [ʐ].[17]

(20)	a.	cerkiew-n-y [tsɛrcɛvnɨ] ‘Orthodox’	cerkw-i [tsɛrkfʲi] ‘Orthodox church’ gen.sg.
	b.	Moskwa [mɔskfa] ‘Moscow’	cf. Russian [maskva]
		Tykwer [tɨkfɛr] personal name	
		Łotwa [wɔtfa] ‘Latvia’	
		mykwa [mɨkfa] ‘mikvah’	
		bar micwa [bar mʲitsfa] ‘bar mitzvah’	
		kwerenda [kfɛrɛnda] ‘query’	
		kwesta [kfɛsta] ‘collection’	
		Kwerfurt [kfɛrfurt] ‘Querfurt’	
		kolokwium [kɔlɔkfjum] ‘colloquium’	

[15] The fact that the [ʐ] alternates with [r] is irrelevant for a phonetically based approach.

[16] Given the morphosyntactic conditioning of the proposed analysis, it would not be a problem if it was discovered that progressive devoicing is in fact restricted to specific morphemes, cf. the discussion of consonant mutations.

[17] In contrast to consonant mutations, assessing the rate of progressive devoicing (an unnatural pattern) in relation to regressive voice assimilation (a natural pattern) is difficult because voicing assimilations are not indicated in dictionary entries or in corpora. Without a doubt, though, progressive devoicing is less common than regressive assimilation for the simple reason that the former process is restricted to /v/ and /ʐ/ in postobstruent position. Regressive assimilation has no similar restrictions. However, the fact that it is extended to borrowings irrespective of their morphological structure is sufficient to grant it a status of a productive and regular phonological process.

c.	kwakier [kfacɛr] 'Quaker'	kwakrzy [kfakʂɨ] nom.pl.
	Dniepr [dɲɛpr] 'Dnieper river'	Dnieprze [dɲɛpʂɛ] loc.sg.
	Cypr [tsɨpr] 'Cyprus'	Cyprze [tsɨpʂɛ] loc.sg.
	czakra [tʂakra] 'chakra'	czakrze [tʂakʂɛ] loc.sg.
	fiakier [fjacɛr] 'fiacre'	fiakrze [fjakʂɛ] loc.sg.
	GOPR [gɔpr] 'Mountain Volunteer Search and Rescue'	GOPRZE [gɔpʂɛ] loc.sg.

In (20) the triggering segment is in preobstruent position, while the obstruent undergoing assimilation is prevocalic. This is diametrically opposite to what licensing by cue would predict. Recall from the scale established for Polish in (18) that prevocalic position is protected as the relevant *αvoice constraint is ranked below Preserve[voice]. Preobstruent position, on the other hand, is not similarly protected. Progressive devoicing calls for a reversal in the ranking of the constraints given in (18).

(21) Ranking of constraints for progressive devoicing (impossible)
*αvoice/V__[+son] >> Preserve[voice] >> *αvoice/V__[-son]

Such a reversal is impossible for two reasons. First, it contradicts the data in (17). Second and more important, the ranking of the constraints is based on a universal perceptibility scale and cannot be reversed (unless purely phonetic conditioning is abandoned and language-specific factors are admitted). It must be concluded that phonological approaches that directly incorporate phonetic content into phonological constructs fail to predict the existence of this pattern.[18]

5. The proposal

The following subsections define the key elements of the proposed markedness-free analysis: lexical storage of allomorphs (5.1) and morphophonological schemas (5.2). The goal of Section 5.3. is to represent Polish consonant mutations and progressive devoicing in terms of markedness-free schemas. Section 5.4 discusses the main implications of the analysis for phonological theories.

5.1. Lexical storage of allomorphs

The idea that storage should be kept to a minimum permeates early generative research. It stems from the assumption that whatever is predictable and derivable by rule should not be stored (i.e. listed). However, Jackendoff (1975) convincingly argues that the storage of predictable information does not preclude the need for redundancy rules used to coin novel words. In a similar vein, Langacker (1987) points out that lists and rules are not mutually exclusive and that, what he calls, the rule/list fallacy should be avoided. Similar views have been expressed and substantiated by, for instance, Bybee (2001) and Booij (2009).

Lexical storage of allomorphs is not a new idea. Some alternations cannot be derived using purely phonological operations and the relevant allomorphs need to be listed. In phonologically conditioned suppletion two phonologically dissimilar alternants need to be stored; however, their distribution is phonologically conditioned (Carstairs, 1988, 1990). Anderson (2008) discusses a pattern from Surmiran and argues that vowel reduction, once a phonologically conditioned process, has become opaque. A solution proposed by Anderson involves reference to two listed alternants of the stem whose distribution is governed by prosodic considerations (stress). The distribution of alternants may also be regulated by phonologically neutral considerations. Paster (2006) and Embick (2010) use subcategorization frames which make reference to phonological and lexical information; however, allomorph selection does not result in phonologically optimized structures. In Kaititj the ergative suffix appears as [-ŋ] after disyllabic stems and as [-l] after trisyllabic stems. Although the formula that captures the generalization makes reference to phonological vocabulary, the syllable, this case of allomorph selection does not in any way improve phonological well-formedness (Paster, 2006).

Baudouin de Courtenay (1927) and Cameron-Faulkner and Carstairs-McCarthy (2000) examined locatives in Polish and argued that the choice of the ending is conditioned by the availability of the alternant of the stem. If a noun has two stem alternants, the locative is formed using *-e*, if a noun has only one stem alternant, the locative ending *-u* is selected.

(22) sy[n] 'son' only one stem alternant [sɨn]: locative sy[n]-u
Nixo[n] 'Nixon' normal stem alternant [ɲiksɔn], special stem alternant [ɲiksɔɲ]: locative Nixo[ɲ]-e
ko[ɲ] 'horse' only one stem alternant: locative ko[ɲ]-u
li[st] 'letter' normal stem alternant [list], special alternant [liɕtɕ]: locative li[ɕtɕ]-e
li[ɕtɕ] 'leaf' only one stem alternant [liɕtɕ]: locative li[ɕtɕ]-u

[18] To account for their discrepant behavior, Gussmann (2007) proposes that /v/ and /z/ in (19) and (20) are in fact sonorants (phonologically). This solution is obviously not available in a phonetically based approach.

Cameron-Faulkner and Carstairs-McCarthy (2000) use the data as evidence that in the case of nouns with alternations in the stem, the two stem allomorphs need to be listed. The existence of such patterns shows two things: allomorph selection need not be phonologically optimizing, and some alternants, including different shapes of a stem, have to be listed. The latter finding is essential for the present purposes because frequency is a property of listed words, rather than morphemes.

5.2. Morphophonological schemas and rules compared

It is vital to compare the relevant aspects of rules and schemas. Schemas in contradistinction to rules emerge from the lexicon, that is, from the stored representations of words and phrases. As a consequence, they have "no existence independent of the lexical units from which they emerge" (Bybee, 2001, 27). Rules, on the other hand, exist independently of the stored items and form part of a module that is separate from the lexicon. The productivity of a schema is a function of the number of participant items (Bybee, 2001). Put differently, the more words comply with a given schema, the more productive the schema is predicted to be. In this view, productivity of a schema is gradient and probabilistic, which is a consequence of the close connection between schemas and stored words. In contrast, rules do not show a direct relationship with the number of words they apply to. In a situation where several rules are applicable, one of them is designated as "default" and productive and the others are predicted to be unproductive (Marcus et al., 1992).

Since the publication of *the Sound Pattern of English* (Chomsky and Halle, 1968), the well-formedness of rules has typically been associated with the notion of markedness or phonological naturalness. Rules that lead to the reduction in markedness are preferred over those that do not. In this view, final devoicing of obstruents is a possible rule, while final voicing is predicted to be impossible, as it would lead to more marked structures (Kiparsky, 2006). However, there is accumulating evidence that undermines the role of markedness as an active bias in synchronic grammars. There is an abundance of processes that result in more marked structures (Anderson, 1981; Czaplicki, 2013; Bach and Harms, 1972; Hale and Reiss, 2008). Typological asymmetries can be explained by extragrammatical factors (e.g. common trajectories of phonetically based sound change) (Ohala, 1983; Blevins, 2004). Insofar as schemas are based on stored representations, they are language specific and not dependent on naturalness, construed as a universal learning bias. Thus, schemas are a priori markedness-free.

Rules traditionally refer to distinctive features (Chomsky and Halle, 1968). If segments are referred to, this is done as a shorthand for the featural specification that underlies a particular segment. Schemas are not similarly restricted in their vocabulary.

(23) Lexical organization provides generalizations and segmentation at various degrees of abstraction and generality. Units such as morpheme, segment, or syllable are emergent in the sense that they arise from the relations of identity and similarity that organize representations. Since storage in this model is highly redundant, schemas may describe the same pattern at different degrees of generality (Langacker, 2000; Bybee, 2001, 7–8)

As mentioned in (23), schemas can refer to various organizational units such as segment, syllable or feature, as long as these units emerge from stored representations. This fragment points to yet another important difference between rules and schemas. Rules are preferably stated using phonological vocabulary (this is a requirement of modularity, Scheer, 2012). In contrast, schemas are formed on the basis of phonological and semantic similarity between stored words. Morphological structure emerges from these identity relations. As a consequence, schemas by default contain information about morphological structure (e.g. English past tense formation using *-ed*) (Bybee, 2001, 23–24). In fact, Bybee (2001, 97–100) argues that segmental alternations display a preference for morphological conditioning over phonological conditioning. She also claims that "once morphological conditioning becomes dominant, it follows that phonological principles, such as patterning based on natural classes, will no longer be applied in the same way as for phonetically conditioned processes" (2001, 105). Put differently, markedness considerations are not relevant for morphologized patterns. Two phonologically similar contexts can give rise to different segmental alternations, as long as the morphological conditioning is different (i.e. two different morphemes).

To sum up, schemas are dependent on stored representations, their productivity (strength) depends on the number of words they derive (type frequency), they are markedness-free, they can be stated at various degrees of generality (e.g. segment, feature, syllable) and they include information about particular morphemes. Supporting evidence for these properties of schemas can be found in, for example, Bybee (2001) (frequency effects), Booij and Audring (2017) (morphological conditioning) and Blevins (2004) (markedness-free generalizations).

Schemas can be product- or source-oriented. An example of a product-oriented schema specifying English Past Tense in verbs like *stopped, begged* and *wanted* is given in (24a) (Bybee, 2001, 126). Source-oriented schemas mention input as well as output. English Past Tense formation can be expressed using the source-oriented schemas in (24b–d). The double arrow is used to indicate the correspondence relation between the base verb and its Past form. Such schemas have two functions: (i) they describe existing Past verbs of this type and (ii) they serve to coin Past Tense forms for novel verbs (Booij and Audring, 2017).

(24) a. a Past verb ends in [t], [d], or [ɨd]
b. […t], […d] verb ↔ [[…t]ɨd], [[… d]ɨd] Past verb
c. […voiced segment] verb ↔ [[…voiced segment]d] Past verb
d. […voiceless segment] verb ↔ [[…voiceless segment]t] Past verb

While Bybee (2001, 126–129) claims that product-oriented schemas are sufficient for the description of most if not all patterns, locatives exemplified in (22) above offer evidence indicating that source-oriented schemas are also necessary. While the locatives of both *Nixo*[n] and *ko*[ɲ] surface with stem-final [ɲ], different endings are selected: *Nixo*[ɲ]-*e* vs. *ko*[ɲ]-*u*. Importantly, a product-oriented schema stating the distribution of the ending would not be helpful, as the stem-final consonant in the two locatives is the same - [ɲ]. In order to discover which ending is applied, we need to look at the stem-final consonant *in the base*: [n] results in the selection of -*e*, while [ɲ] triggers the selection of -*u*. Several source-oriented schemas representing Polish consonant mutations are exemplified in (25).

(25) a. […k] NOUN nom.sg.masc. ↔ [[…tʂ]ɛk] DIM. nom.sg.masc.
[…g] NOUN nom.sg.masc. ↔ [[…ʐ]ɛk] DIM. nom.sg.masc.
[…x] NOUN nom.sg.masc. ↔ [[…ʂ]ɛk] DIM. nom.sg.masc.
[…t] NOUN nom.sg.masc. ↔ [[…t]ɛk] DIM. nom.sg.masc.
[…ɕtɕ] NOUN nom.sg.masc. ↔ [[…st]ɛk] DIM. nom.sg.masc.
b. […k] NOUN nom.sg.masc. ↔ [[…c]ɛm] NOUN instr.sg.
[…g] NOUN nom.sg.masc. ↔ [[…ɟ]ɛm] NOUN instr.sg.
[…x] NOUN nom.sg.masc. ↔ [[…x]ɛm] NOUN intstr.sg.

The schemas in (25) express the formation of diminutives, (a), and instrumentals, (b). The former pattern was illustrated in Section 4.1, the latter can be applied to *kro*[k] 'step', *pró*[g] 'threshold' and *du*[x] 'ghost'. Source-oriented schemas are preferable for describing consonant mutations, as the applicability and type of mutation in the derivative crucially depend on the final consonant in the base. In (25a) base-final velars appear as their mutated alternants before -*ek*. However, at the same time base-final [t] fails to mutate and the cluster [ɕtɕ] depalatalizes to [st] in the same context. So we could not refer to a product-oriented schema requiring that a consonant appear as its palatalized (or mutated, or retroflex) alternant before -*ek*. Rather, the output of the concatenation of a suffix depends on a particular base-final consonant. Before the instrumental suffix -*em*, illustrated in (25b), velar plosives mutate but the fricative remains unchanged. Such arbitrary suffix- and consonant-specific alternations, which abound in Polish, would be difficult to represent as product-oriented schemas[19] (see Gouskova et al., 2015 and Becker and Gouskova, 2016 for more evidence that source-oriented schemas are necessary).

The schemas in (25) are compatible with approaches that assume the existence of multiple cophonologies within one grammar. In this line of research, each morphological construction is associated with its own phonological subgrammar (Booij, 2010; Booij and Audring, 2017; Inkelas, 2014, among others). In other words, each morphological construction has its own phonological properties. As an example may serve pluralization of nouns in Ngiti, a Central-Sudanic language spoken in Congo: "Even though the singular forms have different tonal patterns, all plural forms have a Mid-High tone pattern, the Mid tone being realized on the initial V-syllable and the High tone on the root syllable" (Kutsch Lojenga, 1994, 135).

(26)	singular	plural	
	àba-du	abá-du	'my father(s)'
	abhu-du	abhú-du	'my grandfather(s)'
	adhà-du	adhá-du	'my cowife/cowives'

Irrespective of the tone pattern of the base noun, the plurals in (26) receive the Mid-High tone pattern. It appears that in Ngiti the Mid-High tone pattern is a phonological property of plurals, which is expressible with an appropriate product-oriented schema.

Schemas require that different types of information – phonological, syntactic, morphological and semantic – be simultaneously accessible. This is the fundamental property of Parallel Architecture, a theory of grammar developed by Ray Jackendoff (cf. Jackendoff, 2002). Booij and Audring (2017) provide ample evidence indicating that morphological and phonological information must be accessible at the same time. For instance, English comparative suffix -*er* can only be used when the base is either monosyllabic or bisyllabic with a final light syllable, e.g. *big* – *bigg-er*, *happy* – *happi-er*. Phonological information about the base must be available when the affix is selected. This generalization is not expressible in modular feed-forward models of grammar, where morphological processing precedes phonological processing. Such models in effect proscribe the usage of phonological information by word formation processes.

Formation of derived imperfectives in Polish furnishes an example of a process that requires reference to morphophonological schemas. Derived imperfectives usually denote a repeated activity. In (27), we look at derived imperfectives formed with the suffix -*aj* (the glide of the suffix is suppressed before consonants) (Gussmann, 2007, 284–287).

[19] This could be achieved, for example, by using markedness and faithfulness constraints. As part of such a solution, markedness constraints enforce palatalization as featural agreement between a selected group of consonants and the following vowel. Faithfulness constraints proscribe a feature change between a derivative and its base for another group of consonants. Such constraints would have to operate on arbitrary groups of segments, as recourse to natural classes is not feasible. In addition, these groups of consonants would have to be defined on a suffix-specific basis. While such solutions might in theory be possible, they will not be pursued here, as they are not designed for modeling frequency effects, an important component of the proposed analysis. Instead, I use source-oriented schemas which make reference to segments.

(27)	koniec [kɔɲɛts]	wy-kończ-y-ć [vɨkɔɲtʂɨtɕ]	wy-kańcz-a-ć [vɨkaɲtʂatɕ]
	‘end’ noun	‘bring to an end’	der. imperf.
	dzwon [dzvɔn]	roz-dzwon-i-ć [rɔzdzvɔɲitɕ]	roz-dzwani-a-ć [rɔzdzvaɲatɕ]
	‘bell’	‘ring out’	der. imperf.

The addition of the derived imperfective suffix *-aj* is accompanied by a replacement of the vowel [ɔ] by [a]. Further examples are given in (28).

(28)	za-robi-ą [zarɔbjɔw̃]	za-rabi-aj-ą [zarabjajɔw̃]	rob-ot-a [rɔbɔta]
	‘earn’ perf.	der. imperf.	‘work’ noun
	s-kłoni-ą [skwɔɲɔw̃]	s-kłani-aj-ą [skwaɲajɔw̃]	skłon [skwɔn]
	‘induce’ perf.	der. imperf.	‘bend’ noun
	o-głosz-ą [ɔgwɔʂɔw̃]	o-głasz-aj-ą [ɔgwaʂajɔw̃]	głos [gwɔs]
	‘announce’ perf.	der. imperf.	‘voice’ noun
	s-tworz-ą [stfɔʐɔw̃]	stwarz-aj-ą [stfaʐajɔw̃]	stwor-u [stfɔru]
	‘create’ perf.	der. imperf.	‘creation’ gen. sg.

Gussmann (2007) notes that when perfective verbs show two instances of [ɔ], both of them may undergo a change to [a]. The vowel [ɔ] that is closer to the suffix is obligatorily replaced by [a]. A similar change is optional for the vowel [ɔ] that is further away from the suffix. As a result, two variants of the derived imperfectives are currently in use for some words. This is shown in the middle column in (29).

(29)	u-spokoj-ą	u-spokaj-aj-ą	s-pokoj-u
	[uspɔkɔjɔw̃]	[uspɔkajajɔw̃]	[spɔkɔju]
	‘calm down’	u-spakaj-aj-ą	‘peace’ gen. sg.
		[uspakajajɔw̃]	
	u-osobi-ą	u-osabi-aj-ą	osob-a
	[uɔsɔbjɔw̃]	[uɔsabjajɔw̃]	[ɔsɔba]
	‘personify’	u-asabi-aj-ą	‘person’
		[uasabjajɔw̃]	
	wy-narod-owi-ą	wy-narod-awi-aj-ą	narod-u
	[vɨnarɔdɔvjɔw̃]	[vɨnarɔdavjajɔw̃]	[narɔdu]
	‘deprive of national identity’	wy-narad-awi-aj-ą	‘nation’ gen. sg.
		[vɨnaradavjajɔw̃]	
	o-swobodz-ą	o-swobadz-aj-ą	swobod-a
	[ɔsfɔbɔdzɔw̃]	[ɔsfɔbadzajɔw̃]	[sfɔbɔda]
	‘liberate’	o-swabadz-aj-ą	‘liberty’
		[ɔsfabadzajɔw̃]	
	u-pokorz-ą	u-pokarz-aj-ą	pokor-a
	[upɔkɔʐɔw̃]	[upɔkaʐajɔw̃]	[pɔkɔra]
	‘humiliate’	u-pakarz-aj-ą	‘humility’
		[upakaʐajɔw̃]	

At a first glance, it appears that the vowel [a] of the suffix triggers vowel harmony. This is especially visible in those variants in (29) in which all vowels [ɔ] in the root turn to [a] when the suffix is added. What is interesting, *o-swobodz-ą* ‘liberate’ shows that prefixes are not affected by this replacement, i.e. while both [ɔsfɔbadzajɔw̃] and [ɔsfabadzajɔw̃] are possible, *[asfabadzajɔw̃] is not. The domain of the application of the process seems to be the root. An analysis employing feature spreading would be perfectly valid in a language that exhibits vowel harmony as a process applicable in various phonological contexts, irrespective of morphological structure. However, Polish does not show any other processes that could be subsumed under the category of vowel harmony. To take an example from (29), while the formation of the derived imperfective from *o-swobodz-ą* yields *o-swobadz-aj-ą* and *o-swabadz-aj-ą* with vowel replacement, a similar replacement is not possible for the noun *swobod-a*, i.e. **swobad-a* or **swabad-a*, despite the context of the vowel [a] in the suffix. It is unlikely that a phonologically natural mechanism involving, for instance, feature spreading is called for. Rather, the process is morphosyntactically restricted to derived imperfectives and involves a replacement of [ɔ] with [a] in roots.

The process is fully productive and regular. In fact, Gussmann (2007, 286) mentions that in colloquial speech it is being extended to derived imperfectives with historical nasal vowels, e.g. the colloquial derived imperfective of *włącz-y-ć* [vwɔntʂɨtɕ] ‘switch on’ is [vwantʂatɕ] (with no standard spelling) and that of *nadąż-y-ć* [nadɔw̃ʐɨtɕ] ‘cope’ is [nadaw̃ʐatɕ] (with no standard spelling). Normative grammarians warn against the usage of these forms, arguing that nasal vowels should not be treated on a par with oral vowels and, therefore, should remain unchanged before *-aj*, i.e. *włącz-a-ć* [vwɔntʂatɕ] and *nadąż-a-ć* [nadɔw̃ʐatɕ]. However, this extension to derived imperfectives with historical nasal vowels clearly indicates that the process is productive and its acquisition does not pose any problems for language learners, in spite of its morphosyntactic restriction.

On the basis of the relevant data from (28) and (29), the vowel alternations in derived imperfectives can be stated using the schema in (30) (see Gussmann, 2007, 286 for a similar statement). The schema states that [ɔ] in the base verb corresponds to [a] in the derived imperfective.

(30) [ɔ] verb root ↔ [a] (C_0[ɔ]) [aj] derived imperfective

The material in parentheses is required to ensure that an [ɔ] that is non-adjacent to *-aj* can undergo the replacement as well. The restriction to roots is necessary to make sure that the vowel [ɔ] in prefixes is not affected, e.g. [ɔ-sfabadzajɔw̃], not * [a-sfabadzajɔw̃].

5.3. Representing language-specific patterns in lexicon-based phonology

The patterns discussed in the previous sections require statements that are language-specific and do not appeal to phonological naturalness (i.e. are substance free). The basic assumption is that morphophonological generalizations emerge from the words stored in the lexicon[20] and contain morphosyntactic information. The latter assumption is based on evidence indicating that schemas may have a low scope of application. No premium is placed on broad generalizations. Strong evidence for the application of low-level schemas has been found in language acquisition (Tomasello, 2003; Dąbrowska, 2004a). The results reported in Albright (2002), Albright and Hayes (2003), and Dąbrowska (2004b) demonstrate that adult speakers prefer low-level schemas to more general rules. The following analysis of the two patterns from Polish will also serve to highlight the importance of morphosyntactic indexing of schemas. It will become evident that certain generalizations must be formulated with reference to particular morphemes (suffixes) because the phonological context alone does not determine which pattern is applicable.

Let us first look at consonant mutations. In (31), I consider representative items exemplifying selected alternations and present the schemas that are extracted from them.

(31)
a. [mawpa] nom.sg.fem. ~ [mawpjɛ] loc.sg.fem.
⟹ [[…p]a] nom.sg.fem. ↔ [[…pj]ɛ] loc.sg.fem.
b. [vata] nom.sg.fem. ~ [vatɕɛ] loc.sg.fem.
⟹ [[…t]a] nom.sg.fem. ↔ [[…tɕ]ɛ] loc.sg.fem.
c. [rak] nom.sg.masc. ~ [racɛm] instr.sg.masc.
⟹ […k] nom.sg.masc. ↔ [[…c]ɛm] instr.sg.masc.
d. [rɛŋka] nom.sg.fem. ~ [rɛnʦɛ] loc.sg.fem.
⟹ [[…k]a] nom.sg.fem. ↔ [[…ʦ]ɛ] loc.sg.fem.
e. [krɔk] nom.sg.masc. ~ [krɔtʂɛk] nom.sg.masc.dim.
⟹ […k] nom.sg.masc. ↔ [[…tʂ]ɛk] nom.sg.masc.dim.
f. [ɕfjat] nom.sg.masc. ~ [ɕfjatɛk] nom.sg.masc.dim.
⟹ […t] nom.sg.masc. ↔ [[…t]ɛk] nom.sg.masc.dim.
g. [lʲiɕtɕ] nom.sg.masc. ~ [lʲistɛk] nom.sg.masc.dim.
⟹ […ɕtɕ] nom.sg.masc. ↔ [[…st]ɛk] nom.sg.masc.dim.
h. [kɔmʲin] nom.sg. ~ [kɔmʲiɲaʂ] Agent Noun nom.sg.masc.
⟹ […n] nom.sg. ↔ [[…ɲ]aʂ] Agent Noun nom.sg.masc.
i. [druk] nom.sg. ~ [drukaʂ] Agent Noun nom.sg.masc.
⟹ […k] nom.sg. ↔ [[…k]aʂ] Agent Noun nom.sg.masc.
j. [gwɔs] nom.sg.masc. ~ [gwɔɕnɨ] nom.sg.masc.adj.
⟹ […s] nom.sg.masc. ↔ [[…ɕ]nɨ] nom.sg.masc.adj.

The alternations in (31) highlight an important issue. While the schemas in (a) – (d) yield a consonant that is arguably palatalized before a front vowel, the schemas in (e) – (g) fail to do so. [tʂ] in (e) is a retroflex and retroflexion is not compatible with palatalization. Similarly, [t] remains unchanged before the front vowel in (f). The change /ɕtɕ/ > /st/ in (g) is an instance of depalatalization before a front vowel. The schema in (h) involves the appearance of a palatalized coronal before a back vowel. The schema in (i) shows that a velar consonant in a similar context (a back vowel) does not change. Finally, the schema in (j) encodes the appearance of a palatal consonant before a non-palatal consonant. The lack of phonetic motivation, which is evident for most of the schemas in (31), however, is not a problem for the proposed markedness-free account. Phonological naturalness is irrelevant for the generalizations.

The importance of morphosyntactic indexing can be seen in schemas (31c) – (e), where one consonant has three distinct realizations before an identical vowel in three different morphological contexts (i.e. before three different suffixes). This implies that the choice of a consonant's alternant depends in large part on a particular suffix.

[20] There is solid experimental evidence suggesting that even fully regular words are stored and their storage is a function of their frequency of use, see Baayen et al. (2003) and Bybee (2001).

The schemas in (32) demonstrate the irrelevance of natural classes in this approach. While velars function as a class for the purposes of the locative singular ending (i.e. they come out as alveolars or a retroflex), (a) – (c), no such uniformity is observed before the instrumental singular ending, where the velar stops come out as palatals but the velar fricative remains unaffected, (d) – (f). Thus, it appears that the groups of sounds affected in a particular morphosyntactic context are arbitrary and do not have to share any phonetic (or phonological) properties. This agrees with Mielke (2008), who found that groups of sounds that function together in phonology are language specific, rather than based on some universal (phonetic) criteria.

(32)
a. [rɛŋka] nom.sg.fem. ~ [rɛntsɛ] loc.sg.fem.
⟹ [[…k]a] nom.sg.fem. ↔ [[…ts]ɛ] loc.sg.fem.
b. [nɔga] nom.sg.fem. ~ [nɔdzɛ] loc.sg.fem.
⟹ [[…g]a] nom.sg.fem. ↔ [[…dz]ɛ] loc.sg.fem.
c. [muxa] nom.sg.fem. ~ [muʃɛ] loc.sg.fem.
⟹ [[…x]a] nom.sg.fem. ↔ [[…ʃ]ɛ] loc.sg.fem.
d. [krɔku] gen.sg.masc. ~ [krɔcɛm] instr.sg.masc.
⟹ [[…k]u] gen.sg.masc. ↔ [[…c]ɛm] instr.sg.masc.
e. [prɔgu] gen.sg.masc. ~ [prɔɟɛm] instr.sg.masc.
⟹ [[…g]u] gen.sg.masc. ↔ [[…ɟ]ɛm] instr.sg.masc.
f. [duxa] gen.sg.masc. ~ [duxɛm] instr.sg.masc.
⟹ [[…x]a] gen.sg.masc. ↔ [[…x]ɛm] instr.sg.masc.

What remains to be dealt with is the issue of modeling cases where two (or more) schemas can be identified in a particular morphological context. Recall from Section 4.1 that in such cases the productivity of the two competing patterns is determined by their relative type frequency, i.e. the number of words that a given pattern applies to. A pattern with a higher type frequency is more likely to be productive and gets extended to novel and rare words. In (33) competing schemas before *-arz* for base-final [n] and [k] are considered, together with their type frequencies calculated as a ratio of the number of words that observe a schema to the number of words to which a schema is potentially applicable.

(33)		*Schema*	*Type Frequency*
	a.	[kɔmʲin] nom.sg. ~ [kɔmʲiɲaʂ] nom.sg.masc.	
		⟹ […n] nom.sg. ↔ [[…ɲ]aʂ] nom.sg.masc.	48/53 = 0.91
		[mwɨn] nom.sg. ~ [mwɨnaʂ] nom.sg.masc.	
		⟹ […n] nom.sg. ↔ [[…n]aʂ] nom.sg.masc.	5/53 = 0.09
	b.	[druk] nom.sg. ~ [drukaʂ] nom.sg.masc.	
		⟹ […k] nom.sg. ↔ [[…k]aʂ] nom.sg.masc.	80/86 = 0.93
		[mlɛkɔ] nom.sg. ~ [mlɛtʂaʂ] nom.sg.masc.	
		⟹ [[...k]ɔ] nom.sg. ↔ [[…tʂ]aʂ] nom.sg.masc.	6/86 = 0.07

The schemas with a higher type frequency in a particular context are predicted to be more productive than those whose type frequency is lower. This can be modeled in Optimality Theory in terms of constraints whose relative ranking is conditioned by type frequency, as shown in (34). As for the coronal [n] in (34a), the schema representing a mutation of the base-final consonant before *-arz* is ranked higher than the analogous schema encoding non-alternating [n]. The reverse is true for the velar [k] in (34b).

(34)
a. […n] nom.sg. ↔ [[…ɲ]aʂ] Agent Noun nom.sg.masc. >>
[…n] nom.sg. ↔ [[…n]aʂ] Agent Noun nom.sg.masc.
b. […k] nom.sg. ↔ [[…k]aʂ] Agent Noun nom.sg.masc. >>
[…k] nom.sg. ↔ [[…tʂ]aʂ] Agent Noun nom.sg.masc.

The evaluation of *kajak-arz* ‘kayaker’ in (35) illustrates the formation of novel words with base-final [k], where two schemas are potentially applicable. The schema that is ranked higher (due to a higher type frequency) determines the output.

(35) Evaluation of *kaja*[k]-*arz*

Input: [kajak] + [aʂ]	[…k] ~ [[…k]aʂ]	[…k] ~ [[…tʂ]aʂ]
☞ a. [kajak-aʂ]		*
b. [kajatʂ-aʂ]	*!	

Candidate (b) violates the dominant schema-constraint and is eliminated. Candidate (a) violates the weaker schema of the two and comes out victorious.

The second phonologically unnatural process, progressive devoicing, can be stated in terms of schemas as in (36). The relevant data are repeated for convenience.

(36) a. [ʂɛvɛk] ~ [ʂfɨ]
[marxɛvɲik] ~ [marxfi]
[tsɛrcɛvnɨ] ~ [tsɛrkfʲi]
[bʲitɛvnɨ] ~ [bʲitfa]
⟹ <voiceless obstr>[ɛv]<sonor> ↔ <voiceless obstr>[f]<sonor>

b. [kra] ~ [kʂɛ]
[wɔtra] ~ [wɔtʂɨk]
[dɔtɕɛratɕ] ~ [dɔtʂɛ]
⟹ <voiceless obstr>([ɛ])[r]<sonor> ↔ <voiceless obstr>[ʂ]<sonor>

The schemas referring to [v] ~ [f] and [r] ~ [ʂ] get separate statements and are fairly specific in their scope of application. This agrees with the research cited above suggesting a preference for low-level schemas in both children and adults.[21]

5.4. Implications

The discussion in the preceding sections has touched on several issues which are to a large extent associated with naturalness and which have implications for phonology: non-uniform behavior of front vowels, morphology-phonology interface and learnability.

Front vowels do not behave uniformly with respect to naturalness. The high vowel occurs exclusively in natural patterns, that is, /i/ follows palatal(ized) consonants, while /ɨ/ accompanies non-palatal(ized) consonants. In contrast, the mid front vowel occurs mostly in unnatural patterns, that is, in the majority of cases (more than 60%) /ɛ/ follows non-palatal(ized) consonants. In fact, these numbers make /ɛ/ more similar to the back vowel /a/, which occurs roughly in 50% cases after palatal(ized) consonants, than to /i/. This implies that we must use different tools for regulating the agreement in backness in Ci and Ce combinations. Rubach (2000) does exactly that when he proposes to split the constraints requiring agreement in backness in CV structures: Pal-i and Pal-e. The two constraints have a fixed universal ranking: Pal-i >> Pal-e. This ranking reflects the implicational relationship between the two vowels: if in a language the mid vowel is evidenced to occur with palatali(zed) consonants, the high front vowel will also appear with palatal(ized) consonants. The reverse relationship may not be true. Rubach (2000) provides evidence from Ukrainian, Polish and Russian to support this claim.

(37) a. Ukrainian:
syn [n] 'son' nom.sg. – syn-iv [nʲ] gen.pl. vs. syn-e [n] voc.sg.
b. Polish
głos Ireny [sʲ] 'Irene's voice' vs. głos Ewy [s] 'Eve's voice'
c. Russian
xvost 'tail' – xvost-ik [tʲ] dim. – xvost-e [tʲ] loc.sg.
vs.
tenisist [tɛnʲisʲist] 'tennis player'
xrizantema [xrʲizantɛma] 'chrysanthemum'

The examples in (37a) and (b) show that while palatalization is mandatory before /i/, it does not apply before /ɛ/ in Ukrainian (inside words) and Polish (across word boundaries). The examples from Russian in (37c) show that agreement in backness is required for Ci combinations, while Ce combinations evidence exceptions in this regard. The data in (37) together with the Polish data discussed in this paper suggest that the mid front vowel shows language-specific behavior with respect to palatalization. While in Russian it co-occurs with palatalized consonants (with many exceptions), in Ukrainian it follows non-palatalized consonants. Polish shows the most complex behavior of /ɛ/. Some *e*-initial morphemes co-occur with palatalized consonants, while others with non-palatalized consonants. This finding is in line with research suggesting that groups of segments functioning together in phonological patterns are language specific, as opposed to universal (Mielke, 2008).

[21] Optimality Theory provides an interesting alternative to formulating certain generalizations in terms of schemas. Following the insight of Steriade (1999), progressive devoicing could take the form of constraints like *αvoice on ʐ/[-son]___[+son], meaning: No voicing contrast is allowed on [ʐ] that stands after an obstruent and before a vowel. A similar constraint can be formulated for [v]: *αvoice on v/[-son]___[+son]. Such constraints could then be ranked with respect to other constraints regulating voicing phenomena in Polish. It should be pointed out that the formulation as well as ranking of these two constraints would have to be arbitrary from the point of view of phonological naturalness (i.e. cue availability). For instance, why is voicing contrast protected on [b] in *pros-i-ć* [prɔɕitɕ] - *proś-b-a* [prɔʑba] but not on [v] in *bitew-n-y* [bʲitɛvnɨ] - *bitw-a* [bʲitfa]? Prevocalic position is universally more hospitable to voicing contrast than preobstruent position. It is evident that language-specific and phonologically unnatural constraints would have to be allowed to override and contradict phonetically grounded constraints in this approach as well.

The present discussion has implications for the morphology-phonology interface. The regularities identified in consonant mutations are morpheme specific, which entails that the phonological tools that are used to represent them in the grammar must make crucial reference to individual morphemes. This means that the schemas, rules or constraints that encode them must contain morphosyntactic information, in addition to phonological information about triggers, contexts and outputs. The same segment in an identical phonological context may give rise to a different output when the morphosyntactic context is different, as illustrated in (38).

(38) ⟹ [...k] nom.sg.masc. ↔ [[...c]ɛm] instr.sg.masc.
⟹ [[...k]a] nom.sg.fem. ↔ [[...ts]ɛ] loc.sg.fem.
⟹ [...k] nom.sg.masc. ↔ [[...tʂ]ɛk] nom.sg.masc.dim.

The schemas in (38) are compatible with approaches that assume the existence of multiple cophonologies within one grammar. In this line of research, each morphological construction is associated with its own phonological subgrammar (Booij, 2010; Inkelas, 2014, among others). In other words, each morphological construction has its own phonological properties. Booij (2010, 2018) provide evidence indicating that a morphological construction may have holistic properties, that is, properties that do not derive from its constituents. The cophonologies approach is readily applicable to the discussed patterns of consonant mutations and the vowel replacement pattern in derived imperfectives.

The discussion of consonant mutations and progressive devoicing has brought up the issue of naturalness in phonology. It turns out that unnatural patterns are part and parcel of a linguistic system. This finding brings to light the issue of the learnability of unnatural patterns. Are unnatural patterns learnable, and, if so, are they more difficult to learn than natural patterns? Is learning purely inductive, which would suggest that unnatural patterns are as learnable as comparable natural patterns (e.g. Blevins, 2004) or is learning mediated by some universal biases favoring natural patterns (e.g. Kiparsky, 2006, 2008)? A substantial amount of experimental evidence bearing on this issue has accumulated. However, as noted by Hayes and White (2013), the evidence is inconclusive and "gives no comfort to advocates of either of the two possible extreme positions (all constraints are a priori knowledge/all learning is purely inductive)".

Let us first review some experimental evidence for the learnability of unnatural patterns. Pierrehumbert (2006) analyzes Velar Softening in English, which changes /k/ to /s/. The process is unnatural, with a natural equivalent being the change of /k/ to /tʃ/. However, Pierrehumbert (2006) finds in her experiment that the process is productive. Onishi et al. (2002) in an experiment on artificial languages tested adults on the learnability of a system where /b k m t/ were restricted to the onset, while /p g n tʃ/ appeared exclusively in the coda – or vice versa. The results demonstrate that both phonotactic patterns are learnable. A follow-up experiment used 16.5-month-old infants as subjects and produced similar results (Chambers et al., 2003). In an experiment on adult subjects Pycha et al. (2003) found that vowel disharmony (unnatural) patterns are as learnable as comparable harmony (natural) patterns. With particular relevance for this paper, in an artificial-language experiment Peperkamp and Dupoux (2007) found that adult subjects were successful at learning unnatural consonant alternations (/p, g/ → [ʒ, f] / V ___ V and /ʃ, v/ → [b, k] / V ___ V).

Experimental evidence supporting the opposite view, one that asserts that there is a bias favoring natural patterns, is also substantial. Wilson (2006) looked at palatalization and showed that subjects are more likely to extend a palatalization alternation in one direction (they learned forms with /ke/ → [tʃe], and were tested on forms with /ki/ → [tʃi]) than the other (they learned forms with /ki/ → [tʃi], and were tested on /ke/ → [tʃe]). The preferred direction of extension finds motivation in Wilson's phonetic model and is supported by the results presented in the present paper. Other experiments that showed a bias in favor of the acquisition of natural patterns were reported in, for instance, Wilson (2003), Berent et al. (2007) and Hayes et al. (2009). However, the experiments using adult subjects who are instructed to learn an artificial language have one important shortcoming. The subjects at the time of testing have already learned at least one language, their native language. The impact of the patterns from their native language on the tested artificial language cannot be overlooked. Although the experimenters took every precaution to mitigate the impact of the native language(s) on the experimental results, one cannot be completely sure whether the natural patterns from the native language (given that natural patterns are generally more common in typology than their unnatural correspondents) exert an influence on the subjects' intuitions.

It is claimed that the present analysis overcomes this shortcoming, as the majority of adult Polish language users learned the language in natural conditions and without the prior knowledge of another linguistic system. If naturalness were to play the key role in the process of language acquisition, we might expect the already-mentioned straitjacket effects. In this view, we would predict that unnatural patterns are likely to be gradually eliminated from the language, as successive generations of speakers find them more difficult to learn than natural patterns. This prediction is not borne out by the data at hand. Unnatural consonant mutations and the pattern of progressive devoicing have emerged, constitute a significant portion of segmental alternations, are productive and show no signs of erosion. In fact, we have seen evidence that some natural patterns are being replaced by competing unnatural patterns, which is an indication that unnatural patterns are not only learnable. They are as easy to learn as their natural counterparts, as otherwise they would not be selected. This pattern replacement corroborates and extends the findings of the quantitative analysis by showing that the productivity of a pattern is not a function of its naturalness.

6. Conclusion

Two Polish patterns exhibiting a significant rate of unnaturalness have been closely examined: consonant mutations and progressive devoicing. Low-level schemas were employed in order to capture the regularity and productivity of these patterns. It was argued that such schemas can refer to morphosyntactic information and are substance free, i.e. they do not require phonetic grounding. In order to give substance to the need for representing unnatural patterns in the grammar, a quantitative analysis of consonant mutations has been carried out. An important finding is that individual segments are more accurate predictors of palatality than natural classes. For example, vowel /i/ shows a distinct behavior from both vowels /ɛ/ and /a/. The latter vowels show a similar behavior, despite different specifications in terms of features. Palatality of a mutated consonant also depends on the following suffix, as various suffixes with the same initial segment produce distinct rates of palatality. In comparison, naturalness understood as agreement in backness plays little role in the conditioning of such alternations. The discussion of progressive devoicing has shown that universal phonetic considerations (perceptibility of voicing contrast) may be overridden by language-specific factors. It follows that phonological and morphological theory must be equipped with the appropriate tools to accommodate patterns that are unnatural from the purely phonetic point of view. Finally, the present discussion gives ammunition to advocates of approaches that assume multiple morphosyntactically specified cophonologies within one grammar.

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Appendix A

Suffixes used for calculating the rate of naturalness of consonant mutations.

i1	i2	i3	i4	i5
i/ɨ nom.pl. masc.pers.	i/ɨ nom.pl. non-pers.	i/ɨ dat./loc.sg. fem.	itɕ/ɨtɕ inf.	ista/ɨsta agent noun
i6	i7	i8	i9	e1
ik/ɨk dim.	izm/ɨzm abstract noun	i/ɨ adj. masc.	istɨ/ɨstɨ adj.	ɛ dat./loc.sg. fem.
e2	e3	e4	e5	e6
ɛm instr.sg. masc.	ɛk dim.	ɛ adj.nom.pl. non-masc. pers.	ɛgɔ adj. gen.sg. masc.	ɛts attributive noun
e7	a1	a2	a3	a4
ɛɲɛ action noun	aʂ agent noun	a adj.fem.	ak agent noun	anka fem. noun
a5	a6	a7	a8	C1
atɨ adj.	anɨ adj.	astɨ adj.	arɲa locative noun	sci adj.
C2	C3			
nɨ adj.	ɲik agent noun			

Appendix B

1. Number of palatal and non-palatal outputs according to suffix-initial segment

	i	ɨ	ɛ	a	C	C′	ALL
palatal	101	0	50	95	5	3	254
nonpalatal	0	78	86	103	61	22	350

2. Palatality of output according to base-final consonant

Base-final consonant * Palatality of output Crosstabulation

Count

		Palatality of output		Total
		palatal	nonpalatal	
Base-final consonant	p	15	10	25
	p′	5	1	6
	b	15	14	29
	b′	6	4	10
	m	14	12	26
	m′	3	1	4
	f	11	8	19
	f′	3	1	4
	v	15	9	24
	v′	4	1	5

(*continued on next page*)

(*continued*)

Base-final consonant * Palatality of output Crosstabulation				
Count				
		Palatality of output		Total
		palatal	nonpalatal	
	t	15	17	32
	d	13	16	29
	s	17	10	27
	z	13	10	23
	r	0	28	28
	w	6	21	27
	l	5	6	11
	n	17	11	28
	k	7	24	31
	g	7	16	23
	x	4	21	25
	ts	0	26	26
	dz	1	15	16
	ɕ	9	3	12
	ʑ	8	0	8
	tɕ	13	5	18
	dʑ	9	4	13
	ʂ	2	15	17
	ʐ	0	19	19
	tʂ	0	12	12
	dʐ	0	7	7
	ɲ	17	3	20
Total		254	350	604

3. Number of palatal/nonpalatal outputs according to suffix

Following suffix * Palatality of output Crosstabulation				
Count				
		Palatality of output		Total
		palatal	nonpalatal	
Following suffix	i1	12	3	15
	i2	2	13	15
	i3	11	6	17
	i4	11	4	15
	i5	15	6	21
	i6	14	9	23
	i7	14	8	22
	i8	9	21	30
	i9	13	8	21
	e1	10	5	15
	e2	2	13	15
	e3	2	24	26
	e4	9	19	28
	e5	9	19	28
	e6	10	4	14
	e7	8	3	11
	a1	13	17	30
	a2	11	7	18
	a3	13	20	33
	a4	15	16	31
	a5	4	13	17
	a6	13	6	19
	a7	13	6	19
	a8	13	17	30
	c1	2	30	32
	c2	3	31	34
	c3	3	22	25
Total		254	350	604

4. Number of palatal/nonpalatal outputs according to front/back suffix-initial vowel or palatal/non-palatal suffix-initial consonant

Following front/back * Palatality of output Crosstabulation

Count

		Palatality of output		Total
		palatal	nonpalatal	
Following front/back	front	154	108	262
	back	100	242	342
Total		254	350	604

5. Number of palatal/nonpalatal outputs according to the place of base-final consonant

Place of consonant * Palatality of output Crosstabulation

Count

		Palatality of output		Total
		palatal	nonpalatal	
Place of consonant	labial	91	61	152
	coronal	145	228	373
	dorsal	18	61	79
Total		254	350	604

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