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On natural and probabilistic effects during acquisition of morphophonemic alternations

DIPLOMA THESIS

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CONTENT

1 Abstract

The acquisition of phonological alternations consists of many aspects as discussions in the relevant literature show. There are contrary findings about the role of naturalness. A natural process is grounded in phonetics; they are easy to learn, even in second language acquisition when adults have to learn certain processes that do not occur in their native language. There is also evidence that unnatural – arbitrary – rules can be learned.

Current work on the acquisition of morphophonemic alternations suggests that their probability of occurrence is a crucial factor in acquisition.

I have conducted an experiment to investigate the effects of naturalness as well as of probability of occurrence with 80 adult native speakers of German. It uses the Artificial Grammar paradigm: Two artificial languages were constructed, each with a particular alternation. In one language the alternation is natural (vowel harmony); in the other language the alternation is arbitrary (a vowel alternation depends on the sonorancy of the first consonant of the stem).

The participants were divided in two groups, one group listened to the natural alternation and the other group listened to the unnatural alternation. Each group was divided into two subgroups. One subgroup then was presented with material in which the alternation occurred frequently and the other subgroup was presented with material in which the alternation occurred infrequently. After this exposure phase every participant was asked to produce new words during the test phase. Knowledge about the language-specific alternation pattern was needed to produce the forms correctly as the phonological contexts demanded certain alternants.

The group performances have been compared with respect to the effects of naturalness and probability of occurrence.

The natural rule was learned more easily than the unnatural one. Frequently presented rules were not learned more easily than the ones that were presented less frequently. Moreover, participants did not learn the unnatural rule at all, whether this rule was presented frequently or infrequently did not matter.

There was a tendency that the natural rule was learned more easily if presented frequently than if presented infrequently, but it was not significant due to variability across participants.

2 Theoretical Background

2.1 Morphophonemic Alternations

Morphemes are by definition the smallest meaningful morphological units. Morphological units might appear as affixes within the linguistic system of a language and they may be added at the end of a word as a suffix to form a derivative.
For the grammatical class of verbs, suffixes can determine person, number, mood, tense, and grammatical gender.
Some English examples of verb suffix morphemes from the inflectional paradigm in simple present are provided in (1).

(1) i. *write-s* (indicating 3^{rd} person singular of simple present indicative active form)

ii. *write-* (zero response, indicating 1^{st}, 2^{nd} person singular or 1^{st}, 2^{nd}, or 3^{rd} person plural of simple present indicative active form)

Other languages display a more complex system of morphological suffixes. German examples are provided in (2). The full simple present inflectional paradigm of the verb *schreiben* 'write' is displayed.

(2) i. *schreib-e* (indicating 1^{st} person singular of simple present indicative active form)

ii. *schreib-st* (indicating 2^{nd} person singular of simple present indicative active form)

iii. *schreib-t* (indicating 3^{rd} person singular or 2^{nd} person plural of simple present indicative active form)

iv. *schreib-en* (indicating 1^{st} or 3^{rd} person plural of simple present indicative active form)

It happens that the phonetic realisation of a morpheme can vary depending on its phonological contexts. See for instance the variants of realisation of the English plural morpheme /-s/ in (3).

(3)	i.	[aɪ] - [aɪz]		‘eye – eyes’
	ii.	[bæk] - [bæks]	*[bækz]	‘back – backs’
	iii.	[nəʊz] - [nəʊzɪz]	*[nəʊzz]	‘nose – noses’

In the interface of morphology and phonology there appear different context-dependent variants, which are called allomorphs.
These morphophonemic alternations describe the allocation of these allomorphs. A prominent example are the allomorphs /-z/, /-s/, and /-ɪz/ of the English plural suffix /-s/ (cf. Gussenhoven & Jacobs 2005: 39-43).

In the example of English plural, the allomorphs /-z/, /-s/, and /-ɪz/ are realised for the following reasons.

(4)	i.	/-z/	is the underlying form as in *eye* - *eyes* [aɪ] - [aɪz].
	ii.	/-s/	is used to avoid two adjacent obstruents in the same syllable differing in voicing as in *back- backs* [bæk] - [bæks];a realisation such as *[bækz] is ill-formed.
	iii.	/-ɪz/	is used to avoid two adjacent sibilants in cases such as *nose – noses* [nəʊz] – [nəʊzɪz];a realisation as *[nəʊzz] is ill-formed.

To fully understand the issue, I will to go into more detail. The alternation of the displayed variants of the English plural morphemes depends on their phonological context. Every allomorph ensures a proper English syllable structure. Hence, phonological knowledge is required for the choice of allomorphs.
Within this work I want to refer to the generative account. It assumes that allomorphs are surface realisations that are derived from abstract lexical underlying forms via constraints or rules.[1]

In the following section I want to make clear which knowledge is required to correctly choose an allomorph and how this knowledge is modeled in the framework of

[1] For an alternative view about analogical or usage-based models see Kerkhoff (2004) who compares the assumptions. She found that the acquisition of Dutch voicing alternations is best described on the basis of similarities between lexical items.

Optimality Theory (OT) from Prince & Smolensky (1993).
Phonological knowledge is founded on three components: contrasts, phonotactics and alternations (cf. Hayes 2004). They are associated in a system and can be interpreted in OT.

2.1.1 Interpretation of Phonological Knowledge in OT

2.1.1.1 Contrasts

First of all phonological knowledge consists of contrasts. Hayes (2004) assumes two kind of contrasts, namely phonemic and allophonic ones. Both of them are encoded in the constraint ranking in OT as there is only the ranking of constraints that allows for encoding grammatical knowledge. Under OT there is no underlying phoneme inventory to limit the choice of underlying forms. To differentiate phonemic from allophonic contrasts in general, one has to look at the ranking order of faithfulness and markedness constraints. These are the two kinds of constraints which are used in OT. The first kind are faithfulness constraints that claim faithfulness between input and output. This means that the surface form needs to be identical to the underlying form. Differences are caused by intervening markedness constraints that demand an inconspicuous output form. Markedness constraints root in perception and production. Contrasts between phonemes should be easy to perceive and produce.

For phonemic contrasts, faithfulness constraints have to outrank markedness constraints, as they allow certain structures to appear. On the other hand, if markedness constraints outranked faithfulness constraints, contrasts would be allophonic.
An example for a phonemic contrast is voicing in German onsets. As one can see in (5), only the change of the feature VOICE of the initial segment causes a difference in meaning.

(5)	i.	[b]ass	'bass'
	ii.	[p]ass	'passport'

Therefore, the voicing contrast is phonemic. A high ranked faithfulness constraint ensures the faithful outcome. Whether the input of the initial segment then is either voiced or not, a faithfulness constraint maintains the same value for VOICE in the input and the output. Hence, it allows both underlying [b] and [p] as output and therefore as initial segment.

The other kind of contrast is the allophonic. Allophones are phones that are in complementary distribution. They stand in a narrow phonetic distance and form realisation variants of phonemes. Note that it is analogous to allomorphy: There are allophones and allomorphs that exist due to morphology. But with respect to my topic, I want to concentrate on allophones that are due to the phonological context. A German example is the alternation of [ç] and [x], see (6).

(6)	i.	L[Ɔx]	'hole'
		B[u:x]	'book'
		B[ax]	'stream'
	ii.	L[œç]er	'holes'
		B[y:ç]er	'books'
		B[ɛç]e	'streams'

Note that the velar fricative [x] only appears after back vowel whereas the palatal fricative [ç] only appears after front vowels. Hence, [x] only appears where [ç] does not appear and vice versa. That is the complementary distribution, which is characteristic for allophonic contrasts. The distribution of [ç] and [x| is due to the phonological context and their appearance illustrates an assimilation to the place of the vowels as [x] is more back than [ç] and therefore the one that is chosen after back vowels. Whether [ç] after front vowels or [x] after back vowels, the result is an unmarked outcome. Only a high ranked markedness constraint can favour the unmarked assimilation and a faithful outcome is not favoured because faithfulness is ranked low in hierarchy.

2.1.1.2 Phonotactics

The phonotactic knowledge describes the legal structures of a language. In OT, legal sequences are interpreted as those that are allowed by faithfulness constraints. Markedness constraints, which would normally forbid them, are outranked by the faithfulness constraints (cf. Hayes 2004). As an example, I want to refer to a phonotactic phenomenon, which is known as syllable-final neutralisation. German, for instance, allows voiced obstruents in word initial but not in word final position. For the analysis in OT, Lombardi assumes the constraints in (7) (cf. Lombardi 1999: 270-271).

(7) i. IDOnsLar
is a faithfulness constraint that demands consonants in the onset to be faithful to underlying laryngeal specification.

ii. IDLar
is a faithfulness constraint that demands consonants to be faithful to underlying laryngeal specification.

iii. *Lar
is a markedness constraint that forbids laryngeal features in obstruents.[2]

The ranking IDOnsLar >> *LAR >> IDLar explains the syllable-final neutralisation in German, see tables (1) and (2).

/lo:b/		IDOnsLar	*Lar	IDLar
	lo:b		*!	
F	lo:p			*

Tab. 1: OT-table for input Lob *'praise'*

/bo:t/		IDOnsLar	*Lar	IDLar
F	bo:t		*	
	po:t	*!		*

Tab. 2: OT-table for input Boot 'boat'

Tab. (1) demonstrates that for the coda consonant the markedness constraint *LAR outranks the only relevant faithfulness constraint IDLar, and the final voiced consonant devoices. Tab. (2) demonstrates that the ranking allows faithfulness in the

[2] Lombardi assumes that the laryngeal feature [voice] is a privative feature. Therefore, *LAR demands unvoiced obstruents.

onset as for the onset consonant it is more important to be faithful than to be unmarked. The markedness constraint *LAR that would forbid a voiced obstruent is outranked by the faithfulness constraint IDOnsLar that allows the word initial voiced obstruent (cf. Lombardi 1999: 273-274).

2.1.1.3 Alternations

Alternations are the last part to make up the phonological knowledge. It comprises the knowledge about patterns of alternations. In other words, all realisation variants of every single phoneme in different phonological contexts are expressed in this part of the theory. If morphemes are varying their form with respect to their phonological context, they are adequately named alternations. Those morphophonemic alternations are interpreted as the choice of output candidates that differ from the underlying form in order to meet phonotactic criteria.

As I gave an overview of the required phonological knowledge to describe morphophonemic alternations I want to go back to the examples (3) and (4). The realisation variants of the English plural suffix can be interpreted in OT. In tab. (3) I show the derivation of *backs*. The input to the system is a form /bæk+z/, allomorphs are represented as output candidates [bæks] and [bækz]. A markedness constraint that forbids heterovoiced obstruents in word final position rules out the candidate [bækz] and the winner is candidate [bæks] (example is analogised to Hayes 2004: 163).

/bæk+z/		NoFinalHeteroVoice
	[bækz]	*!
F	[bæks]	

Tab. 3: OT-table for input /bæk+z/

2.1.2 Acquisition of Phonological Knowledge

As the knowledge of contrasts and phonotactics is required to handle alternations it is not surprising that according to the theory the acquisition of contrasts and phonotactics is supposed to precede the acquisition of morphophonemic alternations. In the following sections, I point out the central aspects of acquisition of all three parts; I will present studies and summarise the learning mechanisms that have been investigated for different aspects of phonological knowledge.

I will concentrate mainly on findings concerning the acquisition of alternations: The acquisition of morphophonemic alternation is a central aspect in phonological acquisition, which, until recently, has not received much attention. In recent research this topic has come to the fore. Most of the research is within the framework of OT (cf. Hayes 2004, Prince & Tesar 2004).

2.1.2.1 Acquisition of Phonemic Contrasts as Part of Phonological Acquisition

When children are born, they are able to discriminate non-native vowel and consonant contrasts. Hence, children per se are able to learn every language of the world and to discriminate their language-specific contrasts (cf. Jusczyk 1997: 51-56). Werker & Tees (2002) tested discrimination abilities of English 6-month-olds on a non-native (Salish) phonemic contrast and found them significantly better performing than English adults (Werker & Tees 2002: 122-127).[3]

However, children's sensitivity for non-native contrasts disappears whereas the native contrasts are preserved: During the first year of life, children form the sound system of their native language. There is evidence that 8-month-olds perform significantly worse than 6-month-olds in a discrimination task of non-native contrasts. And by the age of 10 to 12 month the children's discrimination abilities are comparable to those of adults (Werker & Tees 2002: 127-131). By that time they have formed native phoneme categories and display categorical perception (cf. Jusczyk 1997: 46-48).

Peperkamp (2003) assumes prelexical learning algorithms for both allophonic and non-allophonic contrasts which are accessible at an early stage. After perception of segmental categories the child's task is to reduce the inventory of segmental categories to an inventory of abstract phoneme categories. Hence, it is necessary to detect realisation variants of single phonemes – allophonic contrasts. Without lexical knowledge children are able to make use of learning mechanisms that rely on distribution.

Peperkamp's learning algorithm is based on a characteristic of allophones: Allophonic contrasts are in complementary distribution. One variant is realised in one context

[3] Interior Salish is a native Indian language spoken in British Columbia (cf. Werker & Tees 2002: 122).

and another variant is realised in another context. They mutually exclude one another. A distributional analysis is assumed and results in the detection of allophonic contrasts. The algorithm is responsible for listing the segments' immediate contexts and finds those contrast pairs whose left or right contexts have an empty intersection. If a segment appears in the most restricted number of contexts, it will be defined as allophone, others are defined phonemes. As a result, a rule is worked out which describes the relation between phonemes and allophones.

This analysis has already been tested successfully with adults (cf. Peperkamp, Pettinato & Dupoux 2003) and in the acquisition of an artificial language (cf. Peperkamp, Calvez, Nadal & Dupoux 2006). The distributional analysis failed, however, to hold for a child-directed speech corpus (cf. Peperkamp, Calvez, Nadal & Dupoux 2006). Although the process of learning concepts of allophonic and phonemic contrasts is not fully understood yet,[4] there is compelling evidence that language-specific contrasts are acquired during the first year of life.

2.1.2.2 Acquisition of Phonotactics as Part of Phonological Acquisition

As described above the acquisition of phonotactic knowledge requires knowledge of a language-specific ranking of constraints. Hayes (2004) assumes that an ideal underlying algorithm for ranking the constraints needs to fulfil two tasks, basically. First, it should allow legal faithful forms the output directly from the input. Second, it should be able to deal with illegal underlying forms in the input such that it converts them to legal output forms.

In his review of Tesar & Smolensky's Constraint Demotion Algorithm (cf. Tesar & Smolensky 2000) Hayes proves that the algorithm does not cope with the second task (cf. Hayes 2004: 175-176). Under certain circumstances the Constraint Demotion Algorithm accepts illegal structures. Hayes demonstrates that the algorithm's problem is due to high-ranked faithfulness constraints, which ensure that input forms are more likely to be faithfully accepted as output forms.

However, recent research about the early stages of phonological acquisition states the contrary. Initially, the children's output is unmarked: Children prefer unmarked

[4] Peperkamp argues that there are still problems with the algorithm. In the framework of the present thesis, the description of these problems would go to far. For detailed description see Peperkamp (2003): 102-105.

structures over marked and faithful ones. During the acquisition process the children's output gradually becomes more marked and more faithful (cf. Levelt & Vijver 2004, Gnanadesikan 2004). An explanation in OT is that initially faithfulness constraints are ranked low in hierarchy by default and markedness constraints are ranked high in hierarchy. The phonological development then means that faithfulness constraints move upward and outrank specific markedness constraints.

This is the idea with which Hayes (2004) uses to solve the problem with Tesar & Smolensky's algorithm. He proposes that faithfulness constraints are ranked low in hierarchy by default. Hayes justifies that by arguing that missing negative evidence makes this initial status necessary for learning legal output forms. The gradual rise of the faithfulness constraints denotes an approximation by the child's utterances to adult speech (cf. Hayes 2004: 176). Hayes' algorithm is named Low Faithfulness Constraint Demotion (LFCD). The initial state of low-ranked faithfulness constraint is further supported by evidence from Jusczyk et al. (2002) who demonstrated in a Headturn-Preference Procedure that 4;5- and 10-month-olds prefer *triad* lists that respected markedness constraints (e.g. the triad *am, da, anda*, which respects the markedness constraint AGREE(Place) as the [md] is assimilating to [nd]) over lists that respected faithfulness constraints (e.g. the triad *am, da, amda*, which respects the faithfulness constraint IDENT(Place) as the [md] is not assimilating).[5] For a better understanding the possible output forms are shown in tables (4) and (5).

/am+da/		AGREE(Place)	IDENT(Place)
	[amda]	*!	
F	[anda]		*

Tab. 4: OT-table with high-ranked markedness-constraint

/am+da/		IDENT(Place)	AGREE(Place)
F	[amda]		*
	[anda]	*!	

Tab. 5: OT-table with high-ranked faithfulness-constraint

The high-ranking of the markedness-constraint AGREE(Place) in Fig. 2 leads to the outcome [anda], which is preferred by 4;5- and 10-month-olds.

It is already clear that children acquire the native phonotactic knowledge during their first year of life (cf. Jusczyk 1997: 87-90).

[5] *Triads* are concatenations of two monosyllabic artificial words and a bisyllabic word which is a derived combination of these two (cf. Jusczyk et al.: 44-45).

2.1.2.3 Acquisition of Alternations as Part of Phonological Acquisition

At the age of 1 to 5 (and later, cf. Berko 1958, Kerkhoff 2004) children detect morphemes as parts of the language system (cf. Hayes 2004). Along with that they start to understand that there are variants of morphemes. To meet the phonotactics of their language, the child's task is to develop a grammar to predict the relevant allomorph in the adequate context. Until now underlying mechanisms are not fully understood and discussed in research.

The traditional view is that children locate underlying forms and adapt the ranking of faithfulness constraints that are learned for phonotactics to explain alternations.

In a new account so-called 'output-to-output correspondence' constraints are used (cf. Hayes 2004: 186-191). These constraints are similar to general Faithfulness Constraints. The latter demand from the output to be faithful to the input and 'output-to-output correspondence' constraints demand to be faithful to the morphological base.

Hayes refers to child-speech errors that demonstrate illegal phonotactic forms in favour of proximity to the morphological base. During acquisition, children have to backtrack if they adopted allophones as phonemic contrasts (the backtracking problem, cf. Hayes 2004: 188-189). This is possible due to the following mechanism: 'output-to-output correspondence' constraints are high-ranked a priori. If the system meets an alternation the acquisition task is to demote the 'output-to-output correspondence' constraint which otherwise would block the alternation.

Hayes assumes that knowledge of phonotactics is needed and helpful for the acquisition of alternations as they ensure phonotactic well-formedness. Pater & Tessier (2003) support this approach with an experiment in which subjects were more likely to learn an artificial language, which consists of an alternation that ensures phonotactic patterns of their native language English than an artificial language that does not. Their rules are shown in (8).

(8) i. rule that is conform to English phonotactics:
epenthesis of [t] to avoid word-final single lax vowels.
ii. rule that is not conform to English phonotactics:

epenthesis of [ ] to avoid word-final single back vowels.

Hayes (2004) concludes that the phonotactic knowledge acquired during first year of life, and high-ranked 'output-to-output correspondence' constraints provide helpful tools for the acquisition of morphophonemic alternations.

Berko (1958) also showed that children use their phonotactic knowledge to acquire English plural form alternations. A famous aspect of her work was the method. In her well-known Wug-Test she used nonsense material to test for knowledge of morphological rules:

"We know that if the subject can supply the correct plural ending, for instance, to a noun we have made up, he has internalized a working system of the plural allomorphs in English, and is able to generalize to new cases and select the right form" (cf. Berko 1958: 150).

The method of applying rules to nonsense material is often used in practice: In speech therapy (cf. Grimm 2001 for German), in the investigation of normal and impaired language abilites (cf. van der Lely & Ullmann 2001 for English), and in theoririzing (cf. Wilson 2003, Pycha et al. 2003) where artificial languages are used for investigation.
Berko tested the knowledge of English-speaking 4- to 7-year-old children of plurals, and of simple past forms of nonsense words among other derived forms. She showed a picture in which there was one bird-like animal, followed by a picture in which there were two such animals . The instruction was: "This is a wug. Now there is another one. There are two of them. There are two _." The children's responses were transcribed and analysed.
All age groups gave mostly correct answers. There is evidence for the productivity of morphological rules as children never heard these novel words but nevertheless succeeded to form derivatives. Berko assumes that word forms are not stored and memorised holistically as they were not heard before and only can be derived in a rule-based system.
In spite of mostly correct performances Berko found children until the age of 7 who have problems with single allomorphs. Her observation is that children fail to generalise the third plural ending /-ɪz/, see example (4).

Due to required morphological knowledge several researchers have found that learning morphophonemic alternations is a long lasting process. Kerkhoff (2004), for instance, found that by the age of 7, Dutch children still have difficulties with alternations. In her dissertation Kerkhoff investigated productivity of the Dutch syllable-final voicing alternation in novel words. In Dutch /-en/-plurals there are two possible alternants. In the first example the voicing contrast surfaces in plural form, in the second example it does not, see (9).

(9)	i.	[bƐt] - [bƐdən]	'hand – hands'
	ii.	[pƐt] - [pƐtən]	'cap – caps'

Children prefer the non-alternating form. Hence, children produce devoicing errors like in (10).

(10)	i.	[bƐt] - *[bƐtən]	'hand – hands'

Kerkhoff elicited plural forms of novel words such as *[kƐt]*, expecting either the plural form *[kƐdən]* or *[kƐtən]*. Her results show that alternations are produced variably within a phonological environment. Kerkhoff found that children rely on lexical information and assumes that this is the reason for the relatively late acquisition.

In addition to the question when and how long the acquisition of morphophonemic alternations takes place, another central issue in research is what children's representations of alternations look like as soon as they have noticed them (cf. Hayes 2004, Feest 2007).

In general, the children's productions of words differ from those of adults. As pointed out by Kerkhoff (2004), also children's productions of alternations differ from the ones of adults. A central question of children's representations is whether they are comparable to adult's representations. Is a children's representation somewhat un- or underspecified or is it fully specified?

An unspecification would mean that there is no featural contrast at all and that the representation is unspecified compared to the adult's representation. An underspecification, however, means that there can be a specified feature marked in one context and a contrasting unspecified unmarked feature in the other context. This would result in certain asymmetries such that one value of the feature may be limited to certain positions in the word unit whereas another value of the feature is not. And, if fully specified, is the representation accessible for output and is it used by the children?

This is what Feest (2007) investigated with the example of voice/voiceless-contrast in Dutch. Initially, children tend to devoice voiced stops (for details of the devoicing process see Kerkhoff 2004, Feest 2007), but they do not voice voiceless stops. This opposite pattern is found in German and English learning children (cf. Feest: 44-47). Feest argues that at the earliest stage, the representation is indeed unspecified and particular aspects of the representation, such as voiceless stops, are still underspecified at later stages. This is what she demonstrated in her experiments with 20- and 24-month-olds. In a split-screen preferential looking paradigm Feest investigated shorter and slower looking times to a target picture if the target word was pronounced slightly incorrectly. She found this mispronunciation effect in 24-month-olds if voiceless-initial words were mispronounced as voiced-initial words but not vice versa. This means that 24-month-olds do not accept words that have a voiced sound in initial position to be pronounced voiceless, but they do accept originally voiced-initial sounds to be produced voiceless. 20-month-olds accept mispronunciations in both directions. The findings lead to the assumption that by the age of 2 years, children develop an abstract representation of VOICE. The asymmetrical mispronunciation effect suggests that some aspects of the representation remain underspecified. At what age representations of especially the Dutch voice-alternation are fully specified is needed to be investigated in further research.

Findings of Berko (1958), Kerkhoff (2004), Hayes (2004), and Feest (2007) demonstrate that the acquisition of morphophonemic alternations needs high effort and a long time since problems are reported at least until the age of 7.

Hence, it is worth to think about factors that may facilitate the process of acquisition.

2.2 Supporting Factors in Acquisition of Morphophonemic Alternations

As morphophonemic alternations are a considerable and difficult step in phonological acquisition it is assumed that there are supporting factors. In research there is currently a debate on a linguistic bias that possibly favours natural patterns. In the framework of phonological acquisition there are different views on what is natural and what is not. For the purpose of investigation it is indispensable to find a well-founded definition of naturalness. The following section summarises findings from literature and recent research.

A second supporting factor that is discussed refers to statistical cues as children seem to be considerable statistical learners. The subsequent section summarises findings about what distributional and statistical information children are sensitive to and why it could be helpful for phonological acquisition.

To point out how factors may influence the process of phonological acquisition, I refer to investigations that affect all parts of phonological knowledge.

2.2.1 Naturalness

2.2.1.1 Common Views of Naturalness

2.2.1.1.1 Phonetic Grounding of Naturalness

Although there is no general definition of what naturalness is, there are some characteristics that can be attributed to the term.

According to Anderson (1981) a natural rule is grounded in phonetics. It should have its basis directly in principles governing the organs or the sound of speech.

As an example Anderson argues that an assimilation process reflects the general phonetic principle *ease of articulation*. An assimilation process describes how segments change to bear same values of features. The realisation of two segments with the same value of a feature is easier and needs less effort. The organ which is responsible for the feature does not need to realise two moves but only one. Assimiliation processes can appear in both directions progressively or regressively, and adjacent and non-adjacent. I want to give examples for two kinds of assimilation processes.

First, there is the adjacent regressive process of nasal assimilation in German as in

(11).

(11) i. Se[nf] ~ Se[mf] ‘mustard‘

ii. ei[nk]aufen ~ ei[ŋk]aufen ‘to buy’

The place of articulation of the coronal nasal [n] assimilates to the following segment. This segment spreads its value of the PLACE feature to the preceding nasal, hence, the nasal is adjusted. The value [labial] of the segment [f] makes the preceding [n] appear as labial nasal [m], see (8 i). The value [dorsal] of the segment [k] makes the preceding [n] appear as dorsal nasal [ŋ], see (8 ii).

Example (12) shows a non-adjacent progressive vowel harmony process in Turkish (cf. Fery 2004: 94-96, Becker et al. submitted: 2-3).

(12) i. tor[o]k-n[a]k ~ tor[o]k-n[a]k dative of ‘neck’

neck -DAT neck -DAT

ii. tör[œ]k-n[a]k ~ tör[œ]k-n[ɛ]k dative of ‘Turkish’

Turkish-DAT Turkish –DAT

The process bans certain combinations of non-adjacent vowels in a word and is found in many languages (cf. Gussenhoven & Jacobs 2005: 170-176). In Turkish the suffix vowel changes in order to agree in the feature PLACE with the stem vowel.

As two segments share a value of a feature and harmonise, assimilation processes are often called harmony processes.

The aim of such a process is to make segments agree in certain features. The theoretical basis in OT are so-called agreement constraints, which are understood as a subgroup of the faithfulness constraints (cf. Backovic 2000).

I propose that disharmony processes are natural due to a general principle *ease of perception*. A disharmony process is the opposite of a harmony process: it leads to the opposite pattern. Two segments differ in the value of a feature. An example is the optional dissimilation of two adjacent stops or fricatives in Greek, as displayed in (13) (cf. Hume & Johnson 2001: 4).

(13) i. e[pt]a ~ e[ft]a ‘seven’

ii. [fθ]inos ~ [ft]inos 'cheap'

As two differing values of a feature are less economic for the speaker but easier to perceive by the listener (cf. Hume & Johnson 2001: 7-10), I argue for the naturalness of such a process.[6]

As stated by Anderson (1981) natural rules should reflect the phonetic grounding in any way. It should be overt diachronically and synchronically.
There are examples where processes arised as natural ones diachronically but got independent and changed so that they are not natural anymore.

"[...] a phonetic difference, once mechanical but now linguistically determined, may become the basis of a contrast; the rules distributing some such property in linguistic forms may become opaque through the accretion of other, subsequent rules, and may change in content [...]" (cf. Anderson 1981: 514).

As an example for a case like this Pierrehumbert (2002) presents a /k/-/s/ alternation in English word pairs like *electri[k]* and *electri[s]ity*. The rule behind the pattern is the one in (14):

(14) /k/ is fronted and softened before a front vowel.

For explanation of this case Blevins (2006) argues that

"[...] intermediate processes of deaffrication and dentalisation in the history of Romance, along with subsequent borrowing into English, result is an unnatural but clearly learnable and productive pattern" and that the "[...] sound pattern should result in *k/c* or *k/tʃ* alternations, not the *k/s* alternations borrowed from Latin, and is expected to be more general across the lexicon, not restricted to one or two suffixes" (cf. Blevins 2006: 8).

Even though there is a diachronical explanation, the rule is not exhaustive as there are cases, in which a following front vowel does not necessarily end in softening and fronting /k/ to /s/, see (15).

(15) chee[k] – chee[k]y

[6] On the contrary, Pycha et al. (2003) interpret a disharmony process as unnatural.

Nevertheless, Pierrehumbert (2002) demonstrates that the unnatural process is applied to novel words by English adult speakers and therefore highly productive.

For the emergence of naturalness Blevins (2006) assumes that

"[...] when phonetic patterns with these language-internal sources are phonologized, the resulting sound pattern is natural and has a natural history" (cf. Blevins 2006: 7).

Hence, there are three ways how natural patterns are sourced according to Blevins (2004). The natural sound sources are named CHANGE, CHANCE and CHOICE, displayed and summarised in (16).

(16) i. CHANGE: The phonetic signal is misperceived due to acoustic similarities between the speaker's output and the listener's input representations and due to biases of human perceptual system.
ii. CHANCE: The perceived signal is phonologically ambiguous and the listener allocates incorrect underlying form.
iii. CHOICE: The listener forms different underlying representation from the variable input as intended by the speaker.

Also, Hayes et al. (submitted) conclude that phonetic variation and reinterpretation by new generations of speakers strongly influence a language (cf. Hayes et al. submitted: 2).

Another argument for a process being natural is its appearance in many languages of the world. This is a result of the first worked out characteristic of natural processes – their phonetic grounding. If a process is phonetically motivated, it occurs with greater chance in the world's languages (cf. Blevins 2006).

2.2.1.2 Naturalness in Language Acquisition

In recent research naturalness as an important factor in acquisition has come to the fore. First, studies investigate natural versus unnatural patterns in real languages and whether the unnatural patterns are productive. The assumption behind is that unnatural patterns are a part of the Universal Grammar (cf. Chomsky 1965), but to what extent this is the case is still discussed.

Second, there are studies that investigate the learnability of natural and unnatural patterns with artificial languages. They provide a useful instrument for examinations, as they deal with language material which is previously unknown by participants.

2.2.1.2.1 Naturalness as Part of the Universal Grammar (UG)

Hayes et al. (submitted) assume that phonological rules or constraints can be either founded in principles of Universal Grammar (UG) and are therefore natural or they can be unnatural – arbitrary – and are therefore learned from the input inductively. They distinguish between a strong and a weak UG position:

The strong position is that a grammatical rule, which is not fixed in UG, is not learnable. The weak one is that grammatical rules are not fixed in UG and therefore unnatural. They are possible but more difficult to learn as the UG principles favour biased interpretations. So natural patterns are easier to learn as the UG possibly leads the learner's attention in certain directions (cf. Hayes et al. submitted: 3).

Becker et al. (submitted) provide evidence for the strong view. In a corpus analysis of Turkish they found both natural and unnatural patterns. In experiments they demonstrated that the latter one is not generalised to novel words. The unnatural pattern affects dependencies between consonants and vowels: Voiceless obstruents tend to become voiced after high vowels, and the alternation of the voiceless [tʃ] and the voiced [dʒ] appears after back vowels.

The results indicate that Turkish speakers do not adopt a model of purely statistical generalisation as they extend some but not all patterns.

Becker et al. compared their human data with data of an algorithm: the *Minimal Generalization Learner* (MGL) (cf. Albright & Hayes 2003). The algorithm was provided with training data about Turkish sounds, what natural classes they form, and with lists of words. With distributional analyses, the MGL is able to generalise patterns over similar classes of words and is even able to generalise to novel words. As the algorithm is not provided with any kind of bias, it fails to predict the actual human behaviours in Becker et al.'s experiments.

The authors interpret their findings that – although there was a significantly frequent pattern in the lexicon – the observed alternation is not productive because it is highly disfavoured. Becker et al. suggest that a *same-feature constraint* on vowel-consonant interactions is why it is favoured. Due to the constraint a triggering phonetic feature of the consonant has to be identical to the changed feature of the vowel (Becker et al. submitted: 32-33).

As there are also unnatural processes in the world's languages and their productivity could be demonstrated (cf. Pierrehumbert 2002), Hayes et al. (submitted) have doubts about the strong UG position and favour the weak one.

In their real-language experiment they provide evidence for the weak position. They found that Hungarian participants are aware of unnatural patterns in their native language and

"*undervalue* unnatural patterns relative to the strength with which they are manifested in the lexicon" (cf. Hayes et al. submitted: 4).

Just as Becker et al. (submitted), they first ran a corpus analysis of Hungarian and tested the productivity of patterns in novel items later. In the corpus study, Hayes et al. found four stem-ending consonant environments that have a significant influence on the following suffix vowel. All of them favour front vowels and two of them are unnatural (Hayes et al. submitted: 18). They are displayed in (17).

(17) i. Prefer front suffixes when the stem ends in a bilabial noncontinuant.
ii. Prefer front suffixes when the stem ends in a sequence of two consonants.

The other two constraints might be a result of an affiliation between the coronal place of articulation and the front vowels, see (18). Nevertheless, Hayes et al. take them as unnatural as the alternation does not affect the coronal stops [t] and [d].

(18) i. Prefer front suffixes when the stem ends in a sibilant.
ii. Prefer front suffixes when the stem ends in a coronal sonorant.

In a following examination Hayes et al. found all unnatural constraints to be productive as the adult participants applied them to novel items. Hence, the results contradicted Becker et al.'s findings. Hayes et al. assume that this was due to methodological differences – a larger number of items and participants in the experiment with Hungarians – and that there is no absolute limit against unnatural constraints.

However, the productivity of unnatural constraints in the experiment with novel items was weaker than expected on the basis of the Hungarian lexical data. Hence, Hayes et al. argue for a bias against unnatural constraints rather than an absolute limit. So unnatural constraints are somehow undervalued compared to natural ones.

2.2.1.2.2 Learnability of Natural Patterns

The common view is that the more natural an alternation is, the easier it is to acquire. This is interpreted as a consequence of the characteristics worked-out so far, whether it might be a phonetic grounding, some easiness in terms of perception or production or a grounding of natural principles in UG. Some research projects have investigated the learnability hypothesis. The Artificial Language paradigm has proved to be an appropriate method: participants are presented with stimulus material made on the basis of an artificial grammar and afterwards asked for their generalisations to new stimuli. There is the possibility to manipulate the artificial grammar with respect to different aspects such as naturalness because an artificial grammar can consist of natural or unnatural patterns. I now introduce investigations about the learnability of natural patterns.

In line with the UG-based account, Wilson (2006) assumes that a *substantive bias* has a determining influence on the acquisition of phonological patterns.

His idea of the substantive bias is that the acquisition process is guided by a bias based on knowledge of phonetic principles such as ease of articulation and perceptual distinctiveness. The bias leads to favouritism of phonological patterns that are phonetically natural. To become more precise, Wilson assumes that his substantive bias leads to a preference for phonological changes that involve more perceptually similar sounds. He proposes the following:

"[...] knowledge of substance acts as a bias (or prior) that favours phonological patterns that accord with phonetic naturalness. The bias is not so strong that it excludes phonetically unmotivated patterns from being acquired or productively applied. [...] the learner is predisposed toward patterns that are phonetically natural." (cf. Wilson 2006: 947).

On the basis of two experimental studies he provides support for the assumption of a biased model rather than an unbiased one. He compared the outcome of both a biased and an unbiased computational model with the actual outcome in experimental studies. The biased model favoured changes involving more perceptually similar sounds and was found to better match the outcome of experimental studies. Wilson investigated the learnability of a new palatalisation rule of [k] before [e] and found the generalised pattern of palatalisation of [k] before the new context [i]. In addition, a familiarisation with palatalisation of [k] before the context [i] did not lead to the generalised palatalisation of [k] before the new context [e]. This is predicted only by the biased model.

In order to further the assumption of a biased learning model I now present studies that compared the learnability of natural patterns with the learnabilty of unnatural patterns.

Schane et al. (1975) provided evidence for the improved learnability of simple and natural rules. They compared the performance of adults learning an artificial language, in which either a natural rule operated, whose application resulted in a universal simple syllable structure or in which an unnatural rule operated, whose application resulted in a more complex syllable structure. The rules operated at the transition of adjectives and nouns in the artificial languages. Adjectives had either VCVC or CVCVC structure, and nouns had either CVCV or VCV structures. The design of the language allowed to combine adjectives and nouns in that way that the noun is preceded by the adjective. At the transition then either a consonant happened to meet a vowel or two consonants met.
The rules are displayed in (19). In contrast to the unnatural rule, the natural one led to the unmarked CVCV structure which is found in all the world's languages, which is

the first to emerge in child language and which is the outcome of many phonological processes in the world's languages that avoid more complex structures (cf. Schane et al. 1975: 352). The natural rule ensured that the adjective-final consonant was deleted before a noun-initial consonant, see (19 i.). The unnatural rule did the opposite. It deleted the adjective-final consonants if the following noun started with a vowel. The actual outcome then were clusters, see (19 ii.).

(19) i. natural rule:

Consonant Deletion: word-final consonants are deleted before consonants (to avoid clusters).

(C)VCVC# CVCV ~(C)VCV_ CVCV

(C)VCVC# VCV ~(C)VCVC VCV

ii. unnatural rule:

Consonant Deletion: word-final consonants are deleted before vowels (leading to clusters).

(C)VCVC# CVCV ~(C)VCVC CVCV

(C)VCVC# VCV ~(C)VCV_ VCV

Schane et al. found that the natural rule was easier to learn than the unnatural rule. Interestingly, after a longer exposure phase the advantage of the natural rule disappeared and the unnatural rule was learned as well. A possible bias for the natural rule led the participants to learn faster, but the unnatural rule caught up later.

Pycha et al. (2003) discovered that native English speakers with no previous knowledge of a harmony language are able to acquire the natural and simple pattern of a long-distance assimilation process (vowel harmony) and a long-distance dissimilation process (vowel disharmony) in an artificial language easily. The processes ensure that vowels either share or differ in feature values [front] or [back]. within the word unit. The processes investigated by Pycha et al. are the following:

(20) i. Palatal Vowel Harmony (assimilation): stem and suffix V agree in [back].

ii. Palatal Vowel Disharmony (dissimilation): stem and suffix V disagree in

[back].

Pycha et al. found no difference in the acquisition of vowel harmony and vowel disharmony.

Since the authors define *phonetically natural* as an attribute that can be interpreted by means of acoustic observation without the need of a grammar, they interpret a dissimilation process as unnatural. Hence, they come to the conclusion that there is no advantage for learning a phonetic natural process. I assume that the interpretation of the results stands or falls with the definition of naturalness. There is evidence that dissimilation processes do not necessarily need to be interpreted as unnatural rules because the dissimilation process helps the detection of sounds within the acoustic signal, they can be interpreted as natural processes (see section 2.2.1.1.1) as Wilson (2003) did.

In general, Wilson (2003) found a similar pattern to the one of Pycha et al. with consonant harmony and disharmony in an artificial language: He made his subjects learn a consonant harmony process as well as a process of consonant disharmony. The processes refer to feature sharing non-adjacent consonants, see (21).

(21) i. Nasal Consonant Harmony (assimilation): suffix is /-na/ if the final stem consonant is [+nasal].

ii. Nasal Consonant Disharmony (dissimilation): suffix is /-la/ if the final stem consonant is [+nasal].

Subjects learned both of the processes with the same ease. Therefore, Wilson assumes an equally strong cognitive bias for both assimilation and dissimilation, as they are natural processes. Contrary to performances on assimilation and dissimilation the subjects of both Pycha et al. and Wilson had difficulties in learning the following arbitrary rules which are clearly unnatural, as the triggering segment and the suffix to be chosen do not have a connection with each other, see (22).

(22) i. Palatal Arbitrary rule: front or back suffix V is due to a certain mixture of front or back vowels (cf. Pycha et al. 2003).

ii. Random rule: suffix is /-na/ or /-la/ if the final stem consonant is [+dorsal] (cf. Wilson 2003).

In general, naturalness seems to play a role in the acquisition of alternations. However, some studies show that, depending on the method that is applied, there are differing results. Peperkamp & Dupoux (2007) show that in a phrase-picture-matching task adults can learn both natural and arbitrary unnatural rules of an artificial language, whereas in a more demanding picture-naming task they only learned the natural rule (cf. Peperkamp, Skoruppa & Dupoux 2006).

In both experiments, the exposure phase was exactly the same. The natural and unnatural processes involved were the following:

(23) i. first natural rule: intervocalic stop voicing
V[p]V ~ V [b]V
V[t]V ~ V[d]V
V[k]V ~ V[g]V

ii. second natural rule: intervocalic fricative voicing
V[f]V ~ V[v]V
V[s]V ~ V[z]V
V[ʃ]V ~ V[ʒ]V

iii. first unnatural rule: intervocalic arbitrary change 1
V[p]V ~ V[ʒ]V
V[g]V ~ V[f]V
V[z]V ~ V[t]V

iv. second unnatural rule: intervocalic arbitrary change 2
V[ʃ]V ~ V[b]V
V[v]V ~ V[k]V
V[d]V ~ V[s]V

In the easier forced choice picture matching task, Peperkamp & Dupoux found no difference between the natural and unnatural rules. Adults who were familiarised with the natural pattern performed as well as adults who were familiarised with the unnatural patterns. Both kinds of rules have been learned successfully.

With help of the more demanding task of phrase production Peperkamp, Skoruppa & Dupoux found a difference: Although the exposure phase was the same as in

Peperkamp & Dupoux, in this experiment learners of the natural rule performed significantly better than learners of the unnatural rule. Moreover, the unnatural rules were not applied to novel items.
Peperkamp & Dupoux's experiment demonstrates that a completely new definitely unnatural rule can be learned by adults. Previous experiments could not detect this fact (cf. Wilson 2003, Pycha et al. 2003, Peperkamp, Skoruppa & Dupoux 2006) or demonstrated productivity of unnatural patterns that are already used in the participants' native language (cf. Hayes et al. submitted, Pierrehumbert 2002).

More recently, Skoruppa, Lambrechts & Peperkamp (to appear) explored the role of the phonetic distance between allophones as an important aspect of naturalness.
The underlying assumption is that

"alternating sounds tend to be phonetically close to each other, that is, the change between them typically concerns a small number of features" (cf. Skoruppa, Lambrechts & Peperkamp to appear: 2).

Therefore, phonetic distance concerns the actual outcome of a natural rule. The natural rule then ensures a small phonetic distance between the allophones/allomorphs. And indeed, Skoruppa et al. demonstrate that allophones that are a result of only one changed feature are learned faster than allophones that are a result of two or three changed features. There is no difference between the latter two. This is what Skoruppa et al. interpret as a discrete effect rather than a gradient one. They argue for the positive influence of naturalness on acquisition which results in better and faster learning as they could demonstrate that phonetic distance as an aspect of naturalness plays a role.

In recent research concerning the learnability of natural vs. unnatural rules also children were tested. There are contradictory results: Seidl & Buckley (2005) did not find an advantage for natural patterns but Cristiá & Seidl (2008) did.

Seidl & Buckley (2005) tested 9-month-olds with a modified version of the Headturn-Preference Procedure. The children were familiarised with an artificial language that contained either a natural, phonetically grounded, or an unnatural pattern. The investigation was split into two parts, one experiment examined phonotactic restrictions concerning the manner of articulation, see (24), and one experiment examined phonotactic restrictions concerning the place of articulation, see (25). In both experiments the natural pattern was phonetically grounded and appears in the world's languages whereas the unnatural pattern was not. Seidl & Buckley postulate that the latter represented an arbitrary pattern.

(24) i. natural phonotactic restriction (experiment 1):
Fricatives and affricates, but not stops, occur intervocally. Seidl & Buckley refer to intervocalic spirantisation that is found in many of the world's languages that leads to a similar result.

ii. unnatural phonotactic restriction (experiment 1):
Fricatives and affricates, but not stops, occur word-initially. Seidl & Buckley argue for the unnaturalness of this restriction because it is not found in the world's languages.

(25) i. natural phonotactic restriction (experiment 2):
Labial consonants are followed by rounded vowels, coronal consonants are followed by front vowels. The pattern is the result of an assimilation process that concerned the relation between the two initial phonemes of a word.

ii. unnatural phonotactic restriction (experiment 2):
Labial consonants are followed by high vowels, coronal consonants are followed by mid vowels. The pattern is not phontically grounded and not found in the world's languages. This is why Seidl & Buckley argue for its arbitrariness.

In both experiments Seidl & Buckley did not find a difference in the learning behaviour between the natural and the unnatural pattern. They argue against a bias for natural rules, as both rules are learned with the same ease. However, Seidl & Buckley are critical of their results and admit that the unnatural rules may not have been unnatural enough to show a difference. Another possible reason could be that the learning took place under idealised circumstances (cf. Seidl & Buckley 2005: 310).

Unlike Seidl & Buckley, Cristià & Seidl (2008) provided evidence in a Headturn-

Preference procedure that can be interpreted as a bias for natural patterns. They found an advantage for the learning of patterns that involve a set of sounds defined of a single feature compared to a pattern that involved an arbitrary set of sounds that cannot be described with a single feature, see (26).

(26) i. natural rule:
All words begin with nasals or stops. Nasals and stops belong to the natural class of [-continuant].

ii. unnatural rule:
All words begin with nasals or fricatives. Nasals and fricatives do not belong to a natural class and can be described as [nasal] and [- sonorant /+ continuant]

Note that for an artificial language containing the natural pattern the unnatural pattern has been illegal and vice versa.

In an exposure phase 7-month-olds were familiarised with artificial words containing either the natural or the unnatural pattern. In a test phase, novel words with novel onsets of both patterns were presented to the children. Only those children attended to legal and illegal patterns differently whose familiarisation pattern was the natural one. Hence, Cristià & Seidl demonstrated that there is a difference between learning learning natural and unnatural patterns. Only the natural rule could be applied to novel items. Children from the unnatural familiarisation group did not show any preference for neither the legal unnatural nor the illegal natural pattern. Cristià & Seidl argue that the unnatural group did not learn the pattern due to a probable bias that disfavoured the pattern. To persuade themselves that the result is due to a linguistic bias rather than to difficulties in the learning of fricatives (cf. Cristià & Seidl 2008: 217-219), the authors ran a second experiment. Nonetheless, they consider other possible reasons for the failure with the arbitrary rule. They also control for phoneme frequency in the children's ambient language afterwards. Cristià & Seidl proved that the phonemes for the natural rule are more frequent in the children's lexicon than the phonemes used for the unnatural rule. They were able to exclude an explanation based solely on frequency effects.

I refer to frequency of patterns as the probability of occurrence in my work as well.

The importance of distributional and frequency information is discussed in the current debate. To close the section I want to conclude with what I have learned about naturalness in the extant literature.

2.2.1.3 Definition of Naturalness within the Present Work

For the purpose of research of a particular factor such as naturalness it is indispensable to define its characteristics. Considering conflicting definitions in the literature, this is especially important (cf. Pycha et al. 2003, Wilson 2003).

There are many characteristics that are related to the term *naturalness.* It could be demonstrated that the naturalness of a process affects its diachronic emergence as well as its synchronic appearance in the world's languages. Different experimental studies investigated structural aspects of naturalness. That is, that the naturalness can refer to all parts of a general rule like the one in (27).

(27) A ~ B / _C (A alternates to B in the context of C)

That means that a natural rule can say something about the affected unit (A), the outcome unit (B), the responsible context (C) and even about the change itself and the dependencies between all parts.
To conclude with a useful definition for the purpose of my investigation I summarise the characteristics of a natural process; I will assume these in this work:

- A natural process is grounded in phonetics.
- A natural process yields to allophones/allomorphs which stand in narrow phonetic distance to each other.
- A natural process affects a single natural class of sounds rather than an arbitrary grouping of sounds.
- A natural process makes perception and/or production easier.
- A natural process is found in many of the world's languages.
- A natural process is favoured by UG.
- A natural process is learned easily and effortlessly.

A clearly natural process fulfils all of the above characteristics, and the fewer characteristics describe a process the less natural it is. A clearly unnatural process does not have any of these characteristics .

Like natural processes, unnatural processes are processes, which can be easily described in linguistic theory:

"[Unnatural] patterns are clear enough to the linguist (who sees the system "from the outside") but are not characterizable under the theory of UG" (cf. Hayes et al. submitted: 4).

Under the strong view of UG, they are clearly not learnable, since they are outside of UG. However, studies have demonstrated the productivity of unnatural processes in real languages (cf. Pierrehumbert 2002) and the learnability of unnatural processes in artificial languages (cf. Peperkamp & Dupoux 2007). With respect to the extant evidence I favour the weak view of UG, which postulates a bias for natural rather than a limit for unnatural processes. It seems that not all experimental methods are sensitive enough to show the more difficult learnability of unnatural processes (cf. Becker et al. submitted, Peperkamp, Skoruppa & Dupoux 2006).

I would like to emphasise that if an unnatural process is not learned in an experiment, it does not necessarily mean the complete failure: The fact that the pattern is not learned does not exclude the possibility that it is not learned *yet* due to a restricted number of familiarisation items or restricted familiarisation time.
On the other hand, the clear learning advantage for natural patterns turns out in studies that demonstrated easy and fast learning of the pattern. This is demonstrated by both kinds of natural and unnatural process-comparing studies, such that failed to demonstrate the learnability of unnatural processes and such that did not.

2.2.2 Probability of Occurrence

2.2.2.1 Common Views of Probability of Occurrence

In the world's languages it happens that when there is a morphological marker such as the English plural morpheme /-s/ which can be realised as the allomorphs [-z], [s], and [ɪz], some allomorphs occur more and some occur less often in the lexicon. Köpcke (1998), for instance, claims that the English plural allomorph [z] is the most frequent pattern, [s] somewhat less frequent and [ɪz] the least frequent pattern. The patterns are quite reliably derived by a context-sensitive rule, see (4), with a few exceptions, some of which are displayed in (28).

(28)	i.	child	~ child[rən]
	ii.	deer	~ deer[]

The plural marking system of German, however, is far more complex as there are 15 different rules and 21 lists of exceptions. There are 5 main plural markers among others (cf. Köpcke 1998: 306-308), see (29).

(29)	i.	/-(e)n/	Tasse	– Tasse[n]	'cup –cups'
	ii.	/-s/	Auto	– Auto[s]	'car – cars'
	iii.	/-e/	Tisch	– Tisch[ə]	'table – tables'
	iv.	/-er/	Kleid	– Kleid[ɐ]	'dress – dresses'
	v.	umlaut	Br[u:]der	– Br[y:]der	'brother – brothers'

Köpcke also compares the frequencies of these plural markers in the lexicon and concludes that /-(e)n/ is the most frequent one, followed by /-e/, and /-s/, /-er/ and umlaut occurring less frequent.

Köpcke takes other perceptual characteristics, namely cue validity, iconicity, and salience into account and develops the *cue strength* concept for individual plural markers in English and German (cf. Köpcke 1998: 300; 308). It is noteworthy that mainly the frequency-based factors determine the cue strength of the pattern, the type frequency itself and the factor of cue validity. Unlike the salience and iconicity of a pattern,[7] the factor cue validity represents also some component of frequency: The pattern having the highest cue validity is the one that does not occur in other category contexts than the target context (cf. Köpcke 1998: 300-301).

[7] For definition of salience and iconicity see Köpcke (1998): 300-301.

After investigation of *cue strength* for English it turns out that due to their *cue strength* [z] and [ɪz] are the favoured plural markers in English rather than [s]. As [ɪz] does hardly emerge in other contexts than in the context of plural, it has the highest cue validity. However, in contrast to [z] its type frequency is very low, so [z] seems to be the 'best' candidate.
For German it turns out that – taken all factors into account – [(e)n] is the best candidate, whereas an umlaut is the worst.

However, Köpcke adds that the relative sub-strength of each factor is not weighted yet and needs to be investigated in further research. This makes the determination of the exact *cue strength* still difficult.

As described above Köpcke formulates his hypothesis of *cue strength* and argues for a strong influence of frequency-based factors like the probability of occurrence of patterns on the acquisition. This is what is discussed in the following section.

2.2.2.2 Probability of Occurrence in Language Acquisition

In studies of phonological acquisition there is a debate on the influence of probabilistic effects. The idea is that there might be mechanisms to detect distributional information in the lexicon itself. Furthermore, the frequency of lexical information can be used to establish , for instance, morphophonemic alternations.

Statistical information seems to provide a reliable help in phonological acquisition whether it refers to local distributional cues within the word unit or to distribution of patterns across words in the lexicon.
There are findings for both cases. First, children seem to rely on distributional cues within words to learn about the phonotactics of their native language and to form phonemic and allophonic contrasts. Second, an influence of frequency of occurrence in the lexicon on the acquisition of alternations and inflectional morphology is discussed. In the following section I want to summarise evidence for the probability of occurrence playing a role in the acquisition: There is evidence for the children's increased sensitivity to more frequent patterns rather than to less frequent patterns

and the increased ease of acquisition of more frequent patterns rather than of less frequent ones.

Evidence from research about the acquisition of phonotactics demonstrates that children are sensitive to distributional information from early on. And it seems that children are not only sensitive to the probability of occurrence of patterns but also benefit from its knowledge.

The children's sensitivity to probability with which certain patterns occur is established during the first year of life:
Jusczyk et al. (1997), for instance, showed that 9-month-olds listened longer to a list of words which contained more frequently occurring phonotactic patterns than to a list which contained less frequently occurring English phonotactic patterns. 6-month-olds did not do so. Results suggest that between the age of 6 and 9 months children become aware of the probability of occurrence of phonotactic patterns in their native language.
Other studies demonstrate that children are not only sensitive to the occurrence of patterns but also use this knowledge to reach further steps in language acquisition. Jusczyk (1998) summarises the findings in this research field that distributional information about phonotactic patterns is indeed helpful for word segmentation. He also collects findings about the children's sensitivity to occurrence of function words and how this is used to mark bigger units, such as phrases (cf. Jusczyk 1998: 203-207; 209-210).
However, Jusczyk argues that there must be some kind of restriction to the search for distributional information. In fact, the search needs to

"avoid extracting spurious correlations between features that are unrelated to the structure of the target language" (cf. Jusczyk 1998: 210)

and Jusczyk assumes that this could be achieved by means of certain biases.

In experiments with artificial languages, it could be demonstrated that children are able to extract underlying representations from phonological alternations solely on the basis of distributional information in the input as long as the involved pattern is

natural in the sense of section 2.2.1.3 and appears in complementary distribution:
White, Peperkamp, Kirk & Morgan (2008) investigated whether children are able to form abstract underlying representations solely via distributional information provided by surface forms during their first year of life. In their experiments they familiarised 8.5- and 12-month-olds with artificial languages that contained either a stop or a fricative voicing alternation which are in complementary distribution. The triggering segment was the last one of the artificial determiner preceding an artificial noun whose first segment changed due to the rule. Both alternations were assimilation processes (cf. White et al. 2008: 244-245) and could be determined as natural processes (see section 2.2.1.3). Afterwards, they found preferences for the one or the other pattern in both age groups, assuming that children were aware of what they have been familiarised with.
But so far it remained unclear whether they were only aware of transitional probabilities or whether they also grouped alternating segments to abstract underlying representations. Therefore, in subsequent experiments White et al. investigated whether children in both age groups have formed underlying representations of what they learned. They familiarised both age groups with both alternation patterns just as in the previous experiments. However, during the test phase it was observed whether the children's behaviour was different when they were only presented with alternations in novel nouns, but without the triggering determiner. Without determiners the children's knowledge of distributional cues is not enough to detect the alternations, it is not even helpful as additional knowledge on abstract representations would be. The results suggest that by the age of 8.5 months children have not formed representations, yet. By the age of 12 months, however, children distinguished the pattern they just learned from an unknown one. White et al. conclude and extend their approach from allophony to allomorphy:

> "The present results suggest that distributional learning is a viable strategy for acquiring phonological alternations, like allophony or allomorphy, that are characterized by patterns of complementary distribution. [...] and [this] is consistent with the growing body of work demonstrating that infants are highly capable statistical learners" (cf. White et al. 2008: 258).

There are several investigations whether the childrens' output reflects the probability of occurrence of patterns in the input – and by that their presumed lexicon. On the basis of this assumption Köpcke (1998) argues for the account of schema learning. On the basis of the cue strength hypothesis Köpcke argues for a schematic component in which rules and lexical representations are not separate during the acquisition. With a reanalysis of Berko's (1958) data he proved his hypothesis and therefore the influence of probability of occurrence on the acquisition of plural markers.

Whereas Berko (1958) analysed her data solely within a rule-based account, Köpcke reanalysed them within an analogy-based one. Berko found that some English plural allomorphs were learned better and faster than others but she had also many zero responses in her data. This is what Köpcke investigated under his view as he notes that:

"similarity of test items to plural schemata played a crucial role in performing the task" (cf. Köpcke 1998: 298).

His theory assumes that children rely on schemata rather than rules when they form plurals of novel singulars. To do so, children match concrete forms onto the most appropriate schema, whether it be a singular or a plural one. The schemata again are determined by *cue strength*. Note that the *cue strength* is mainly influenced by frequency effects. Taken the type frequency that means that if a pattern occurs frequently, it will have a high *cue strength* and will thereby provide a good schema for forming new derivatives.
This is how Köpcke explains the many zero responses in Berko's and also others' data: It happens that if a novel singular form shows chararacteristics of a plural schema (e.g. ending in a sibilant), it is more likely to be interpreted as a plural form and therefore just repeated if the plural form is asked for.

If I take the age of acquisition of certain patterns into account, there is more evidence for frequency effects during language acquisition. It is found that the most frequent pattern is also the first to be acquired.
For instance, it turns out that the most frequent [z] is acquired before the less frequent [s]. The last allomorph to be acquired is the infrequent [ɪz] (see Köpcke 1998: 304). The assumption is that the acquisition of plural suffixes is somehow correlated to their *cue strength*, at least corresponding to their hierarchy of probability of

occurrence.

Szagun (2001) investigated the order of acquisition of German plurals in a longitudinal study and corresponding to the five main plural forms in (26) it turned out that the most frequent [(e)n] is indeed the first to be learned. The second most frequent pattern /-e/ follows, whereas the least frequent patterns [s], [er], and umlaut are acquired more slowly and later (Szagun 2001: 122).

This correlation between probability of occurrence and age of acquisition provides more evidence for the probability of occurrence's influence on language acquisition.

For the overall influence of frequency Tomasello (2003) argues:

"Presumably, an important factor [...] is simply the frequency with which children hear a linguistic construction" (cf. Tomasello 2003: 173).

Therefore he summarises cross-linguistic evidence for frequent patterns that are the first ones to be acquired compared to less frequent patterns. He mentions passive constructions in English that are acquired quite late in their fully established form with the prepositional phrase and earlier in a truncated form. This mimicks the children's input, and so the probability of occurrence in the English lexicon. On the contrary he reports that there are languages in which the reverse development is observed, namely when the input reflects the opposite pattern. More evidence is provided by a study that manipulated the input for children in that way that they were frequently presented with complex constructions leading to an unusually early acquisition of these constructions (cf. Tomasello 2003: 173-175, and references therein).

The literature so far, argues for the clear assumption, that probability of occurrence indeed plays a role in language acquisition: The more frequent a pattern occurs, the easier it is to acquire.
What recent research demonstrated is that children are sensitive to distributional information whether it is within the word unit or across the whole lexicon. Nevertheless, researchers admit that the frequent occurrence of a pattern does not

make it necessarily learnable. The influence of biases is discussed.

Hayes et al. (submitted) demonstrate that the assumption is compatible with the framework of generative phonology. They propose a so called Law of Frequency Matching, which determines that speakers rely on lexical frequencies when tested on variable lexical patterns (cf. Hayes et al. submitted: 6, and references therein).

They argue that under the strong view of UG, the law holds only for natural patterns. And because there is no learning without the help of UG, the law does not affect unnatural patterns (cf. Hayes et al submitted: 8). The authors, who favour the weak view of UG, propose in line with this that

"[...] people make [various deviations] from the baseline Law of Frequency Matching, one might be a principle that phonological constraints learned inductively should be taken less seriously than those backed by UG principles" Hayes et al (submitted): 38.

2.2.2.3 Definition of Probability of Occurrence within the Present Work

According to morphophonemic alternations, the probability of occurrence of alternations in the lexicon might be helpful for their acquisition. Note that the definition of probability of occurrence is not as imprecise as the definition of naturalness.

To sum up, the plain idea is that it happens that some alternation patterns are very frequent in a lexicon while others are not. The presumed implications for the acquisition are that the more often an alternation is occurring in the lexicon, the easier it is to detect and acquire. Conversely, the alternation is detected and acquired more difficulty, if the pattern occurred less frequently.

3 Central Issue

As several studies could demonstrate the influence of naturalness as well as the influence of the probability of occurrence on acquisition of (morpho-)phonological patterns, there is the issue of how these factors relate to one another.

There is experimental evidence that there are several factors which might facilitate phonological acquisition and especially the acquisition of morphophonemic alternations.

Statistical cues are investigated and are often discussed in recent research. Primarily, the probability of occurrence of sound structures plays a role. For the case of morphophonemic alternations, learning mechanisms based on the probability of occurrence of the alternation in the lexicon come to the fore.

However, experimental studies suggest that there is a linguistic bias that might constrain these probabilistic analyses. The bias might favour the acquisition of natural patterns over unnatural ones.

With the results from current research in mind, I propose that naturalness as a linguistic bias plays a more important role, given the advantage of the natural rule after a short exposure phase. But current research also suggests that any rule, whether natural or unnatural, could be learned as long as the learner gets enough exposure. Therefore not only the effect of naturalness but also of probability of occurrence shall be investigated in this work.

In the research field the method of Artificial Grammar Paradigm is widely accepted. It provides an adequate base for my purposes: the investigation of the factors which influence the acquisition of morphophonemic alternations.

4 Experiment

Current research in this field suggests that the Artificial Grammar paradigm provides an appropriate method for my purposes.

It requires two experimental phases: During an exposure phase participants are confronted with lexemes of an artificial language. This language contains particular alternations. During the test phase the task of the participants is to extend the acquired implicit knowledge to new items.

Research projects using the Artificial Language paradigm show that participants are able to detect regularities quickly (cf. Wilson 2003, Pycha et al. 2003). The knowledge is implicit most of the times as participants are not able to describe the pattern they have learned. The paradigm shares a characteristic with natural language acquisition: the absence of negative evidence. This is why I chose to do my research within the Artificial Language paradigm.

To investigate the influence of *naturalness* and *probability of occurrence* on the acquisition of morphophonemic alternations I collected independent measures in four groups of stimuli.

The stimuli consist of patterns, which were manipulated in terms of naturalness and probability of occurrence. The variable of *naturalness* was represented by the alternation based on a *natural* vs. an *unnatural* rule. A process of non-adjacent vowel harmony acts as the natural process. An arbitrary rule is taken as the unnatural rule (see section 4.2.2.2). The variable of *probability of occurrence* is represented by the occurrence-patterns of the particular alternation either *frequently* or *infrequently*. This led to the following group characteristics:

NF – **n**atural and **f**requent

NI – **n**atural and **i**nfrequent

UF – **u**nnatural and **f**requent

UI – **u**nnatural and **i**nfrequent

I will refer to these group names below.

4.1 Hypotheses

The central issue of this work was the influence of *naturalness* and *probability of occurrence* on the acquisition of morphophonemic alternations. First, does naturalness affect the acquisition of the alternation and is there a bias that favours natural alternations rather than unnatural ones? Second, does the probability of occurrence have influence on the acquisition of alternations and is there evidence that rules that appear more frequently are acquired with more ease than rules that appear less frequently? Third, is there evidence that one of the two factors is more important than the other?

My hypotheses are the following:

Hypothesis 1: There is no effect of naturalness nor of probability of occurrence on the acquisition of morphophonemic alternations.

Hypothesis 2: There is only an effect of naturalness on the acquisition of morphophonemic alternations.

Hypothesis 3: There is only an effect of probability of occurrence on the acquisition of morphophonemic alternations.

Hypothesis 4: There is an effect of both naturalness and probability of occurrence on the acquisition of morphophonemic alternations. Both of them are equally strong.

Hypothesis 5: There is an effect of both naturalness and probability of occurrence on the acquisition of morphophonemic alternations, with probability of occurrence being more important.

Hypothesis 6: There is an effect of both naturalness and probability of occurrence on the acquisition of morphophonemic alternations, with naturalness being more important.

4.2 Method

4.2.1 Participants

93 participants have been tested. All of them are adult native German speakers with normal hearing and normal or corrected-to-normal vision. They have been recruited from the experimenter's environment and among the students of University of Potsdam. All volunteered to participate. To ensure that there is no previous knowledge of a harmony language each participant had to fill in a language history questionnaire, which was used to see if the participant had contact with a harmony language.

One participant needed to be rejected because of knowledge of a harmony language, namely Arabic.[8]

12 participants failed the procedure including the implicit learning task. Their performances during the test phase could not be analysed for the following reasons:

- more than 10 null reactions
- usage of incorrect plural endings
- lack of understanding of the task

The remaining 80 participants have been randomly assigned to four groups NF (N=20), NI (N=20), UF (N=20), and UI (N=20).

Their mean age was 22.8 years, ranging from 18 to 50. 62 participants were women, 18 were men.

The participants' educational history ranged from German secondary education certificate (10 years of school education) to doctor's degree. None of them had background in Linguistics. For a detailed list of participant's characteristics see appendix A.

[8] In Arabic, vowel harmony seems to occurr only in adjacent context (cf. Watson, 1995). Nevertheless, the participant with knowledge of this language was excluded.

4.2.2 Stimuli

Two independent artificial languages λ1 and λ2 were designed. λ1 was the natural language and λ2 the unnatural one.

4.2.2.1 Commonalities of λ1 and λ2

The following properties were the same in λ1 and λ2:

- There are only nouns in singular and plural form.
- Each singular form consists of a CVC-stem and no further affix.
- λ1 and λ2 have the same singular forms.
- A picture of an object from the Snodgrass & Vanderwart collection was randomly assigned to each singular item (cf. Snodgrass & Vanderwart 1980); the grey-scaled set of the collection was used (cf. Rossion & Pourtois 2004). The object illustrated the meaning of the word form. Therefore, each plural form was prepared with two appropriate object pictures. See appendices B and C for a complete list of singular forms and their meanings.
- For plural forms one of the two suffix allomorphs [y] and [u] is linked. Hence, the plural form consists of the syllable structure [C1V1.C2V2].
- For construction of words of the languages, only German phonemes will be used (cf. Kohler 1999).
- All words satisfy German phonotactics.
- A phoneme which is used for one position in the word is not used for another one.

The following list explains why certain phonemes are chosen in certain positions.[9]

C_{1A} properties:
All possible sonorants from the German phoneme inventory were used. Therefore, they share the feature [+sonorant]. The sonorant /ŋ/ could not be used because of a phonotactic constraint which does not allow /ŋ/ in word-initial position (see Féry

[9] In this section I use the classification of distinctive features as described in Féry 2004, 77-141.

2000). The phonemes realized by certain phones are listed as follows:

/m/	realized by	[m]:	[+cons]	[-vow]	**[+son]**	[-cont]	[nasal]	[labial]
/n/	realized by	[n]:	[+cons]	[-vow]	**[+son]**	[-cont]	[nasal]	[coronal]
/j/	realized by	[j]:	[+cons]	[+vow]	**[+son]**	[+cont]		[dorsal]
/l/	realized by	[l]:	[+cons]	[-vow]	**[+son]**	[-cont]		[coronal]

C_{1B} properties:

A choice of possible obstruents from the German phoneme inventory was applied. Therefore, they share the feature [-sonorant]. A variation in terms of features PLACE, CONTINUATION, and VOICE was confirmed. The following phonemes, realized by certain phones, were chosen:

/f/	realized by	[f]:	[+cons]	[-vow]	**[-son]**	[+cont]	[labial]	[-voi]
/z/	realized by	[z]:	[+cons]	[-vow]	**[-son]**	[+cont]	[coronal][ant]	[+voi]
/d/	realized by	[d]:	[+cons]	[-vow]	**[-son]**	[-cont]	[coronal]	[+voi]
/k/	realized by	[k]:	[+cons]	[-vow]	**[-son]**	[-cont]	[dorsal]	[-voi]

V_{1A} properties:

A choice of possible front vowels was applied, as all of them share the feature [front]. They vary in terms of features HEIGHT and TENSENESS. The number of high and tensed vowels is equal in V_{1A} and V_{1B}. Hence, I chose phonemes and phones as follows:

/ɪ/	realized by	[ɪ]:	[-cons]	[+vow]	[+son]	[high]	**[front]**		
/e/	realized by	[e]:	[-cons]	[+vow]	[+son]		**[front]**		[+tense]
/œ/	realized by	[œ]:	[-cons]	[+vow]	[+son]		**[front]**	[rounded]	

V_{1B} properties:

All possible back vowels from the German phoneme inventory were applied. Hence, they share the feature [back]. Like the phones of V_{1A} the vowels vary in terms of features HEIGHT and TENSENESS. The German phoneme /a/ sometimes remains unclear concerning the critical feature [back].[10] Thus, /a/ was excluded from the λ1

[10] cf. Féry 2004, 89-90.

and λ2 phoneme set.

/ʊ/ realized by [ʊ]: [-cons] [+vow] [+son] [high] **[back]**[rounded]
/o/ realized by [o]: [-cons] [+vow] [+son] **[back]**[rounded] [+tense]
/ɔ/ realized by [ɔ]: [-cons] [+vow] [+son] **[back]**[rounded]

C_2 properties:
A choice of possible obstruents and the only left sonorant /ŋ/ from the German phoneme inventory was applied. A variation in features PLACE, CONTINUATION, and PLACE was confirmed. Due to the effects concerning final devoicing in German[11] only voiceless obstruents were chosen:

/p/ realized by [p]: [+cons] [-vow] [-son] [-cont] [labial] [-voi]
/s/ realized by [s]: [+cons] [-vow] [-son] [+cont] [coronal][ant] [-voi]
/ʃ/ realized by [ʃ]: [+cons] [-vow] [-son] [+cont] [coronal] [-voi]
/t/ realized by [t]: [+cons] [-vow] [-son] [-cont] [coronal] [-voi]
/ŋ/ realized by [ŋ]: [+cons] [-vow] [+son] [-cont] [nasal] [dorsal]

V_2 properties:
Two vowels were chosen whose only difference is the feature [front] and [back]. They agree in features of HEIGHT, ROUNDNESS, and TENSENESS:

/y/ realized by [y]: [-cons] [+vow] [+son] [high] **[front]**[rounded] [+tense]
/u/ realized by [u]: [-cons] [+vow] [+son] [high] **[back]** [rounded] [+tense]

The outcome of the restrictions is summarized in tab. (6).

<table>
<tr><td>C_1</td><td>V_1</td><td>C_2</td><td>V_2</td></tr>
<tr><td>m, n, l, j
[+sonorant]</td><td>ɪ, e, œ
[front]</td><td rowspan="2">t, s, ʃ, p, ŋ</td><td>y</td></tr>
<tr><td>f, d, k, z
[-sonorant]</td><td>o, ɔ , ʊ
[back]</td><td>u</td></tr>
<tr><td colspan="3">singular form ($C_1V_1C_2$)</td><td></td></tr>
<tr><td colspan="4">plural form ($C_1V_1C_2V_2$)</td></tr>
</table>

Tab. (6)

[11] cf. Féry 2004. 64-66.

As there is phonotactic constraint against /ŋ/ after tense vowels (cf. Féry 2000), those items were removed from the matrix of possible lexemes in λ1 and λ2. Tensed vowels are [e] in V_{1A} and [o] in V_{1B}. Due to their comparable distribution in V_{1A} and V_{1B} the same number of items with critical characteristics were removed.

4.2.2.2 Differences between λ1 and λ2

The difference between the languages λ1 and λ2 results from the rule that generates the plural form. The following rules explain the morphophonemic alternation of the suffix /-y/ and /-u/, see (30).

(30) i. natural rule (λ1): vowel harmony
The suffix is [-y], a front vowel, if the stem vowel is [front].
The suffix is [-u], a back vowel, if the stem vowel is [back].
ii. unnatural rule (λ2): arbitrary
The suffix is [-y], a front vowel, if the initial stem consonant is [+sonorant].
The suffix is [-u], a back vowel, if the initial stem consonant is [-sonorant].

Vowel Harmony is a phonological process found in many languages of the world.[12] In phonological research, vowel harmony is considered to be a natural rule. According to my definition vowel harmony also fulfils the characteristics of a natural rule (see section 2.2.1.3).
Hence, the application of the rule (1) makes λ1 be a natural language.

The arbitrary phonological process of rule (2) is not found in the languages of the world. According to my theses in section 2.2.1.3 rule (2) does not fulfil the characteristics to be natural. Therefore, λ2 is an unnatural language as rule (2) is applied.

[12] Examples of harmony langauges are Finnish and Akan, cf. Gussenhoven & Jacobs 2005, 170-172.

Neither the natural nor the unnatural rule is found in German. And no participant had previous knowledge of a harmony language.

The design of the languages allows the construction of lexica for λ1 and λ2. Each lexicon contains 224 singular nouns and 224 plural nouns. The singular forms are the same for λ1 and λ2. For a full list of singular forms see appendix D. The plural forms differ due to the application of the natural or unnatural rule. For a full list of plural forms of λ1 and λ2 see appendices E and F.

4.2.2.3 Preparation of Item Sets

For each group NF, NI, UF, and UI a group-specific item set for exposure phase was prepared. In addition, there was one item set for the test phase, which was the same for all groups.

To ensure a learning effect the items of the the test phase set must not be a subset of the items of the exposure phase set. Otherwise a positive result could be interpreted as an indication of memorization rather than learning:

„If an alternation completely fails to generalize beyond attested forms, it suggests that these forms are learned individually and that no abstract generalization over them is formed. If the alternation is aggressively and reliably extended, even to forms which differ substantially from attested forms, it follows that a very broad abstraction has been formed." (Pierrehumbert 2002: 2)

Only those singular word forms were kept for the test phase whose C_2 is /s/ and /p/ (n = 96). The choice based on C_2 was important because there were no consequences on λ1 and λ2 plural forms. Their generation depends on characteristics of C_1 (for λ2) or V_1 (for λ1). Hence, for both languages half of the items will need the /-y/ suffix, and the other half needs the /-u/ suffix. For testing the 96 items were presented in the same random order to all participants.

For the preparation of exposure phase item sets I proceeded as follows:
The remaining singular forms whose C_2 is /t/, /ʃ/, and /ŋ/ (n = 128) provided a basis for the sets.

Group NF and NI had to listen to λ1 material, which includes the alternation formed by the natural rule. Group UF and UI had to listen to λ2 material, which includes the alternation formed by the unnatural rule. Differences within subgroups NF and NI, and UF and UI were according to the occurrence of the alternation.

The subgroup was presented with material in which the appropriate alternation occurred frequently: participants of subgroups NF and UF listened to stimulus material which consisted of 50% plural forms (with alternation) and 50% singular forms (without alternation).

The other subgroup was presented with material in which the alternation occurred infrequently: participants of subgroups NI and UI listened to stimulus material which consisted of 75% singular forms (without alternation) and 25% plural forms (with alternation).

The group and stimulus design is summarized in tab. (7).

base for stimulus material	λ1 (natural rule)		λ2 (unnatural rule)	
groups	NF	NI	UF	UI
plural forms	50%	25%	50%	25%
singular forms	50%	75 %	50%	75%
occurrence of alternation	frequent	infrequent	frequent	infrequent

Tab. (7)

Each item set consisted of 128 items, each of which is presented twice to each participant. To counterbalance the characteristics over all items in one group, the items were listed according to their characteristics first and separately randomized:

- singular forms
- plural forms with C_{1A} and V_{1A} (λ1 / λ2)
- plural forms with C_{1A} and V_{1B} (λ1 / λ2)
- plural forms with C_{1B} and V_{1A} (λ1 / λ2)
- plural forms with C_{1B} and V_{1B} (λ1 / λ2)

To prepare exposure phase item sets for the frequent groups NF and UF, I chose 64 singular forms and 16 language-appropriate plural forms out of each list. For the infrequent groups NI and UI, I chose 96 singular forms and 8 language-appropriate

plural forms out of each list. The final presenting order was prepared by randomizing the collection of forms, respectively.
For each group NF, NI, UF, and UI a second exposure phase item set was prepared with the same properties according to language material and number of alternation-containing items. Hence, effects of sequences were excluded. Finally I had prepared 8 exposure phase item sets, 2 for each group NF, NI, UF, and UI.

4.2.3 Equipment

A female native German speaker using normal prosody recorded all items. The recording of stimuli took place in an anechoic room at the University of Potsdam. I used the facilities of the university and worked on sounds using the software Praat version 5.0.19 (cf. Boersma & Weening 2008). All sounds were cut and their volume was normalized to 70 dB.
To present the stimuli and to record the responses of the participants I used an Apple MacBook with Mac OS X version 10.5.6 operating system. The computer was provided with software programmes Microsoft®Powerpoint for Mac Version 11.5.1 and Audacity® 1.3.5d. Microsoft®Powerpoint is a software which can present visual and auditory stimuli simultaneously. Performances of the participants were recorded and digitised with Audacity®, which is a digital audio editor.
A Logitech® PC Headset 120 with headphones and a microphone was used, as well.

4.2.4 Procedure

The procedure was the same for all groups NF, NI, UF, and UI. Each participant was randomly assigned to one of the eight subgroups and took part in a subgroup-specific exposure phase. This was followed by the test phase, which was the same for all groups.
The experiment took place in a quiet room using the headphones, microphone and the computer. For further descriptions of equipment see section 4.2.3.

4.2.4.1 Exposure Phase

First of all the participant was told that he will listen to words of a new language.[13] While listening to these auditory stimuli he was shown pictures that refer to the auditory stimuli's meanings. The task was to pay attention and to listen carefully. No further explanations were given for the implicit learning task.

During the exposure phase each participant was presented with the set of stimuli prepared for his group. Each stimulus was presented for 2 seconds. He was listening to auditory stimuli via headphones and watching the visual stimuli presented on the computer screen.

For the purpose of familiarisation with the procedure there was a short introduction with 6 German examples. Its progress was the same as the exposure phase with new language items. The introductory items of German were arranged as follows:

Auge (engl. eye) - *Röcke* (engl. skirts) - *Stern* (engl. star) - *Sterne* (engl. stars) - *Rock* (engl. skirt) - *Augen* (engl. eyes).

For a schematic illustration of the progression of exposure phase see fig. (1).

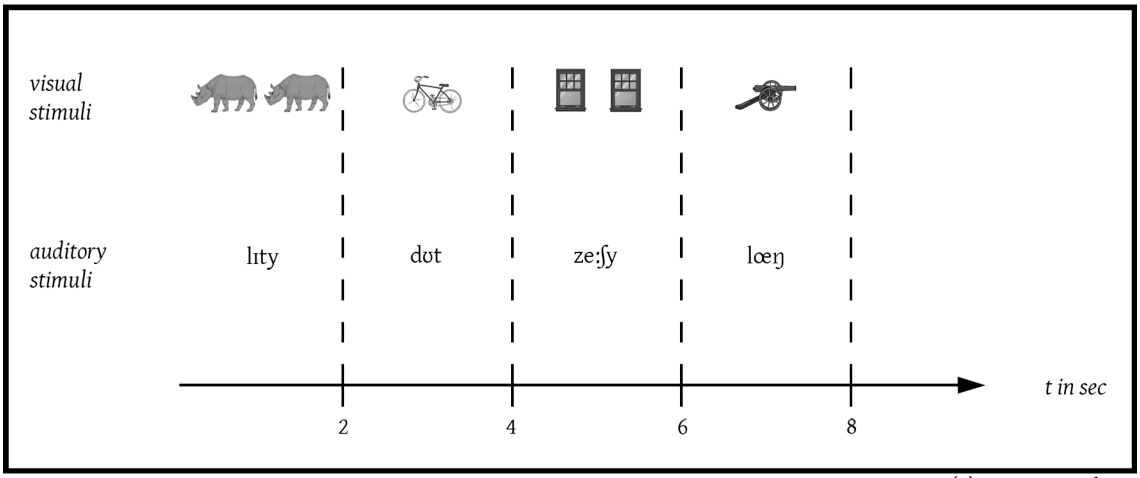

Fig. (1): exposure phase

4.2.4.2 Test Phase

The participants were told to be tested in their abilities in the new language. After being presented with a new word and picture of the language the participants' task now was to produce an adequate plural form themselves.

[13] I use the male pronoun to refer to a participant whether it was a man or a woman.

The singular forms from the subset for the test phase were presented for 2 seconds. Simultaneously a picture to which the singular form was assigned was shown on screen.
Between each new stimulus there were 3 seconds, in which there was only a visual stimulus: The object shown directly before now occurred twice. Also, a question mark was added. This led participants to produce a plural form. So the singular form was given and by adding a suffix the participants formed the plural.
The procedure was held for all items of the testing set (n = 96) including two breaks after every 32 stimuli.
The speech performances were recorded and kept for purposes of analysis.
For a schematic illustration of the progression of the test phase see fig. (2).

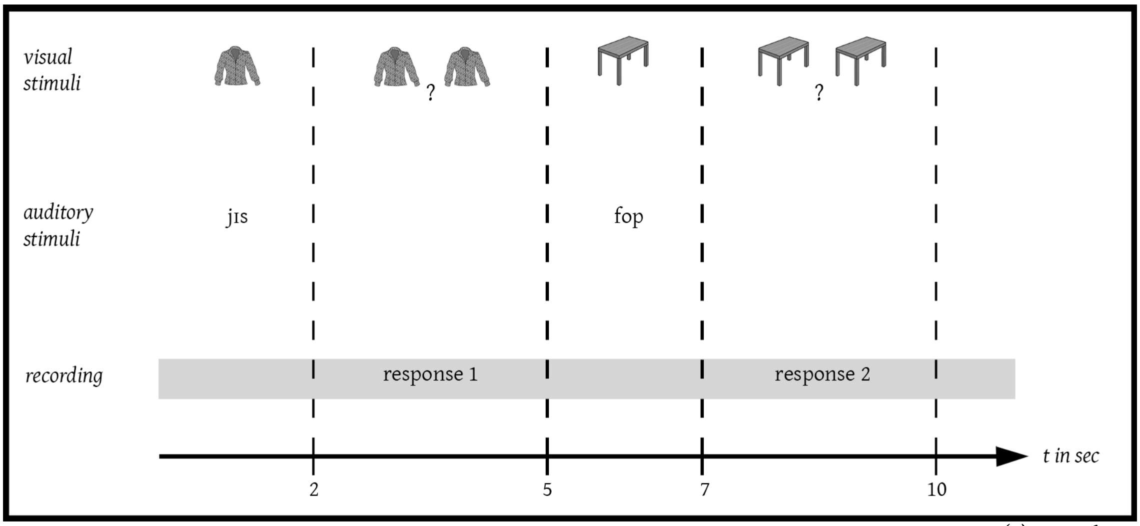

Fig.(2): test phase

4.2.5 Predictions for the Experiment

Taking the design of the experiment into account, different predictions can be made according to the hypotheses.

Hypothesis 1: There is no effect of naturalness and probability of occurrence on the acquisition of morphophonemic alternation.
Prediction: There should be no main effect or interactions at all. All group performances should bet he same: NF = NI = UF = UI.

Hypothesis 2: There is only an effect of naturalness on the acquisition of morphophonemic alternation.
Prediction: There should be a main effect of naturalness: The natural rule should be learned easier than the unnatural one: NF, NI > UF, UI.

Hypothesis 3: There is only an effect of probability of occurrence on the acquisition of morphophonemic alternation.
Prediction: There should be a main effect of probability of occurrence: The frequently presented rule should be learned easier than the infrequently presented one: NF, UF > NI, UI.

Hypothesis 4: There is an effect of both naturalness and probability of occurrence on the acquisition of morphophonemic alternation. Both of them are equally strong.
Prediction: There should be main effects of naturalness and probability of occurrence: The natural rule should be learned easier than the unnatural one. The frequently presented rule should be learned easier than the infrequently presented one. Moreover there should be an interaction: The easiest to learn is a frequently occurring natural rule. Somewhat less easy to learn is an infrequently occurring natural rule. To learn a frequently occurring unnatural rule should be as easy than the latter one and, finally, hardest to learn should be infrequently occurring, unnatural rules: NF > NI, UF > UI.

Hypothesis 5: There is an effect of both naturalness and probability of occurrence on the acquisition of morphophonemic alternation, with probability being more important.
Prediction: There should be main effects of naturalness and probability of occurrence: The natural rule should be learned easier than the unnatural one. The frequently presented rule should be learned easier than the infrequently presented one. Moreover there should be an interaction: The frequently occurring natural rule should be the easiest, followed by the frequently occurring unnatural one. Less easy to learn should be the infrequently occurring natural rule, followed by the hardest to learn infrequently occurring unnatural rule: NF > UF > NI > UI.

Hypothesis 6: There is an effect of both naturalness and probability of occurrence on the acquisition of morphophonemic alternation, with naturalness being more important.
Prediction: There should be main effects of naturalness and probability of occurrence: The natural rule should be learned easier than the unnatural one. The frequently presented rule should be learned easier than the infrequently presented one. Moreover there should be an interaction: The easiest to learn is a frequently occurring natural rule. Somewhat less easy to learn is an infrequently occurring natural rule. Even less easy to learn is a frequently occurring unnatural rule and, finally, hardest to learn are infrequently occurring, unnatural rules: NF > NI > UF > UI.

4.2.6 Analysis

All responses were recorded. I analysed the recordings by documenting the plural word performances of each participant. I distinguished between productions of [y] alternations, productions of [u] alternations and other productions.
The accuracy of plural forms containing the [y] alternation and those containing the [u] alternation was counted: I identified their appearance in the wrong or the right context.
The total number of correct answers of each participant was analysed with respect to the number of correct answers that had been possible.
The performances of the single participants were grouped according to affiliation with their subgroups NF, NI, UF, and UI.

Two independent variables, namely *naturalness* and *probability of occurrence*, have been manipulated. There were two conditions for each variable. The variable of *naturalness* would consist of the conditions *natural,* if language λ1 (containing the natural rule) was applied - and *unnatural*, if language λ2 (containing the unnatural rule) was applied. The variable of *probability of occurrence* consisted of the conditions *frequent* and *infrequent*, depending on the occurrence of the alternation during exposure phase. I did independent measures for the groups: there were different participant groups for each of the conditions as summarized in tab. (8). Hence, an analysis via unrelated two-way analysis of variance was appropriate (cf. Greene & D'Oliveira 2003: 146-154).

For the analysis I used the languageR from the software package R (cf. Urbanek & Iacus 2008).

		variable: naturalness	
		condition: *natural*	condition: *unnatural*
variable: probability of occurrence	condition: frequent	**NF:** natural/frequent	**UF:** unnatural/frequent
	condition: *infrequent*	**NI:** natural/infrequent	**UI:** unnatural/infrequent

Tab. (8)

4.2.7 Results

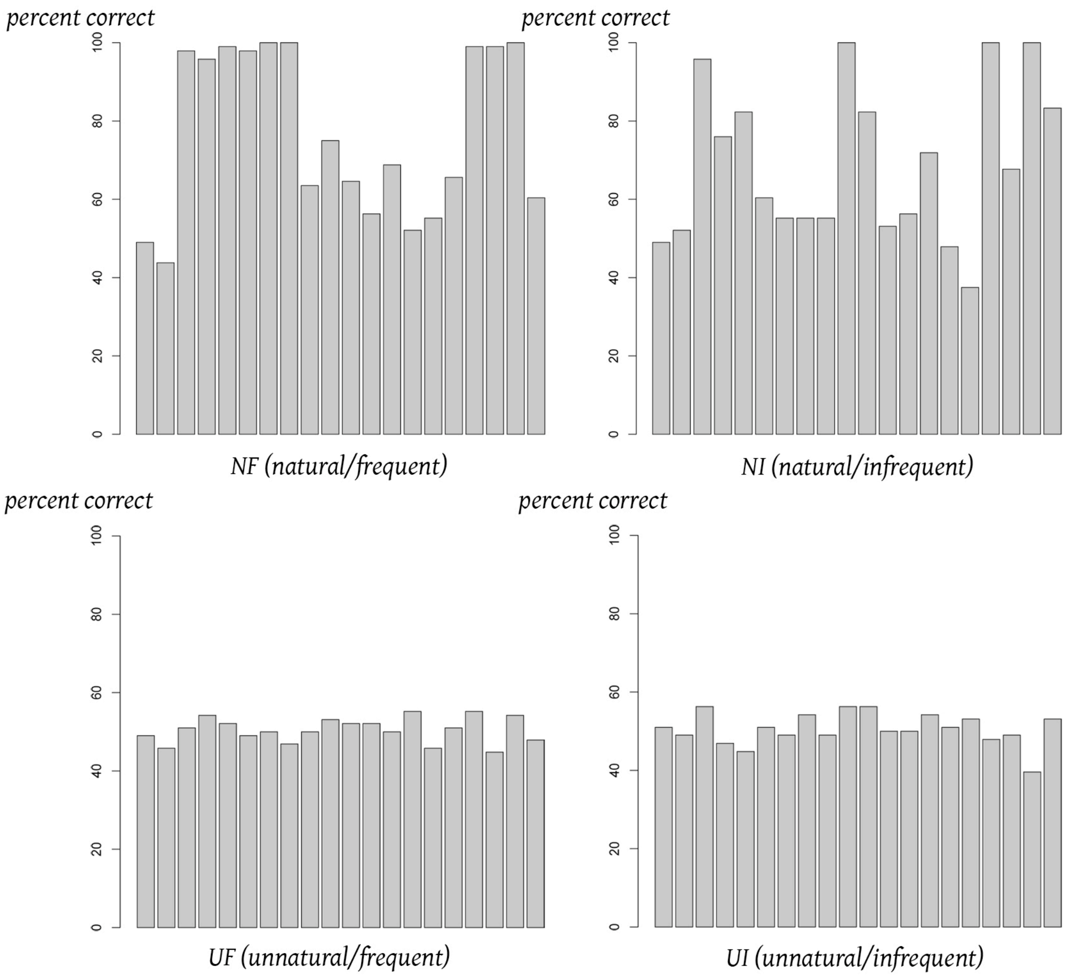

Fig. (3) individual results

Participants showed significantly better learning effects in conditions with the natural rule than in those with the unnatural one. There were no significant differences along with the manipulation of the factor probability of occurrence. Single results are displayed in fig. (3), for detailed single results see appendix G. Tab. (9) shows the mean for all conditions and their standard deviation.

Group	NF	NI	UF	UI
Mean number of correct responses (n_{total} = 96)	74.05	66.30	48.45	48.55
Mean percent correct	77.14	69.06	50.47	50.57
Standard deviation	20.30	18.95	3.02	3.95

Tab. (9)

Fig. (4) displays the same values as a plot.

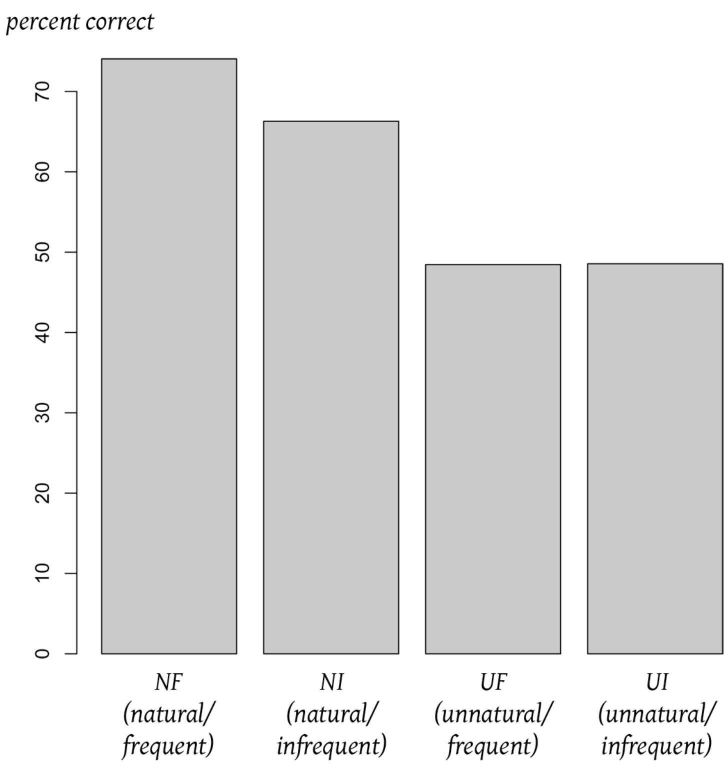

Fig. (4) mean values

The statistical analysis has entailed the following results:
An unrelated two-way analysis of variance revealed a main effect for *naturalness* ($F(1/76) = 47.226$, $p < .01$), but no main effect for *probability of occurrence* ($F(1/76) = 1.471$, $p = .229$). I could not find a significant interaction between *naturalness* and *probability of occurrence* ($F(1/76) = 1.549$, $p = .217$).

Post-hoc tests (unrelated T-Test) revealed significant differences between both the conditions NF (natural/frequent) and UF (unnatural/frequent) ($t = 5.58$, $df = 19.84$, $p < .01$), and NI (natural/infrequent) and UI (unnatural/infrequent) ($t = 4.10$, $df = 20.65$, $p < .01$). Also, the difference between NF and UI was significant ($t = 5.52$, $df = 20.44$, $p < .01$), and so was the difference between NI and UF ($t = 4.16$, $df = 19.96$, $p < .01$).

Post-hoc tests (unrelated T-Test) within the natural and unnatural conditions remained not significant: The difference between NF and NI was not significant ($t = 1.25$, $df = 37.82$, $p = .220$), also the difference between UF and UI was not ($t = -0.09$, $df = 35.53$, $p = .929$).

4.3 Discussion

I found a main effect for naturalness providing evidence that the factor plays an important role in the acquisition of morphophonemic alternations. Some, but not all participants were able to learn the natural rule whereas no participant was able to learn the unnatural rule, as none of their performances was above chance level.

I did not find a significant effect for probability of occurrence. Regardless of this statistical result I want to point out that there is a tendency for the frequently presented natural rule to be learned easier than the infrequently presented natural rule.

Hence, I propose that this factor also plays a role. I assume that the effect did not show up within my experiment because of variance in performances. Fig. (5) displays the amount of variance in the data.

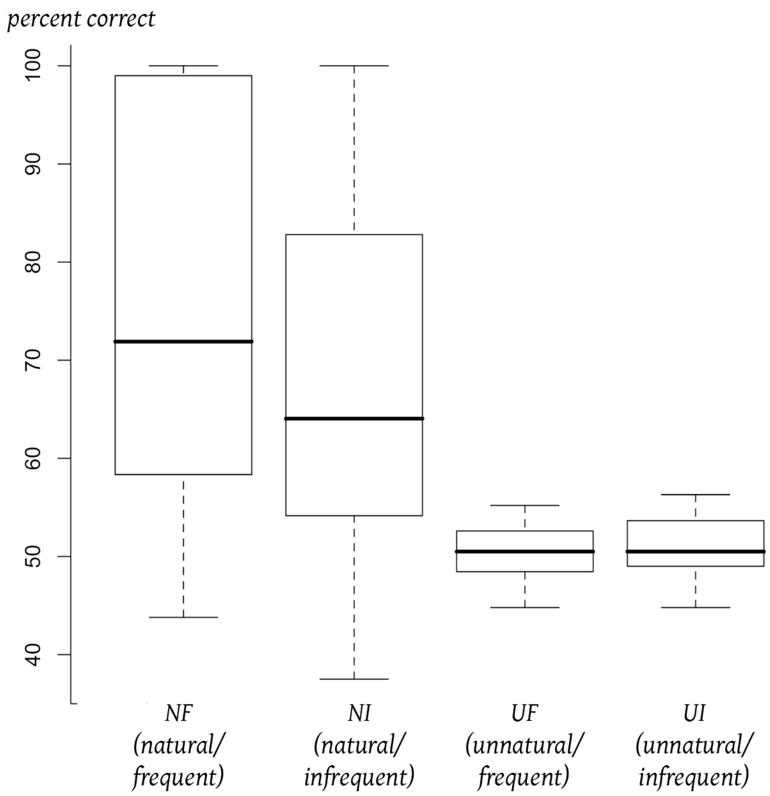

Fig. (5) variance around the means

My results are consistent with Hypothesis 2. Only naturalness as a decisive factor in acquisition of morphophonemic alternation was confirmed. However, as pointed out, there is a tendency that also probability of occurrence is playing a role. Overall, the results imply that naturalness is the more important factor: Participants showed sensitivity to the manipulation of factor naturalness across groups and not to the manipulation of probability of occurrence.

5 Conclusion

The intention of my work was a direct comparison between two factors that influence the acquisition of morphophonemic alternations, namely naturalness and probability of occurrence.

The central issue was to weight both factors and to find out whether (a) one factor may be more important than the other and (b) this factor therefore has greater impact on learnability of morphophonemic alternations.

In my experimental work I compared the learnability of two phonological rules within an artificial languages. The rule concerned the alternation of a plural suffix.

The first rule was a natural rule, namely vowel harmony. Front and back suffixes [y] and [u] were to be chosen according to the place feature of the stem vowel.

I have decided on this rule as it is widely considered to be a natural rule. It fulfils the typical characteristics of a natural rule: It is grounded in phonetics and reflects the general phonetic principle *ease of articulation*. Vowel harmony is a rule found in many of the world's languages. As outcome of the natural rule ideally leads to phonetically similar allomorphs, I controlled for the largest possible similarity between the allomorphs. The segments concerned all belong to the natural class of vowels. It is a suffix vowel that aligns to the stem vowel. And apart from that vowel harmony is said to be favoured in UG.

The second rule was an unnatural rule. Front and back suffixes [y] and [u] were to be chosen according to the sonorancy of the first consonant.

The rule is clearly unnatural, as to my knowledge it is not found in any of the world's languages. There is no apparent reason for it to be grounded in phonetics as it reflects no general phonetic principle such as *ease of articulation* or *ease of perception*. In other words there is no reason why a suffix vowel should change due to the sonorancy of the first stem consonant.

The rules' probabilities of occurrence were strictly controlled during the exposure phases. In addition, for each rule there was a group that was presented frequently and another group that was presented infrequently with that particular rule. The acquired knowledge was examined in a picture-naming task in all groups. The evaluation of the adult participants' performances allowed to compare the influence of naturalness and probability of occurrence on the acquisition of morphophonemic alternations.

I found that naturalness has a strong influence on the acquisition, whereas the probability of occurrence has no influence.

The vowel harmony was detected and learned to different degrees by participants who were familiarised with it. Some applied the rule 100 percent correctly and some performed at chance level. None of the participants that were familiarised with the unnatural rule showed any learning effect at all, as they all performed at chance level and the infrequent or frequent presentation did not make a difference.
The comparison between frequent and infrequent presentation within the natural groups suggests that there is a tendency for the more frequently presented rule to be learned more easily, but the result did not reach significance. Note that there was a large amount of variance in the data and that the frequent condition contained 50 percent alternation patterns and that the infrequent condition contained 25 percent alternation patterns during the familiarisation. The difference might have been too small to show a difference in performance.

To sum up, it could be demonstrated that natural rules are learned, unnatural ones are not. A pure learning without a bias does not explain the advantage for the natural rule.
Overall, my results support recent findings about the learning advantage of natural rules over unnatural rules. In line with an UG-based account (cf. Becker et al. submitted, Hayes et al. submitted) I interpret my findings that way that there must be a principle of UG that is responsible for the difference. Along with Hayes et al. I assume that

"If participants consistently generalize in some particular directions and not in others, a plausible inference is that some UG principle is guiding the process of generalization" (Hayes et al. submitted: 3).

In the present case, that means that an UG principle favours the acquisition of the natural process of vowel harmony over the unnatural arbitrary process.
Although Hayes et al. further argue that

"[...] learners are able to detect the unnatural context, but give them less credence when they form their final grammar" (cf. Hayes et al. submitted: 36).

Participants in the present experiment obviously did not learn the arbitrary rule. This is concluded from their performances at chance level. None of them reported a detected strategy.

For the time being the present results do not necessarily support the weak view of UG by Hayes et al. as the unnatural rule was not learned at all. Moreover, the results can support Becker et al.'s strong view, which proposes that an unnatural rule is clearly unlearnable. Becker et al. (submitted) suggest an UG-determined *same-feature constraint* on vowel-consonant interactions. Due to the constraint a triggering phonetic feature of the consonant has to be identical to the changed feature of the vowel (Becker et al. submitted: 32-33). This is not the case for the present arbitrary rule. That means that the non-compliance with the *same-feature constraint* can call to account for the arbitrary rule that was not learned.

Nevertheless I still favour the weak view, which does not exclude my data as long as I propose that it was due to methodological restrictions that I failed to demonstrate learning of the arbitrary rule. For instance, if the participants had familiarised with the unnatural pattern more frequently and during a very long exposure phase, they might have learned the rule, as well.

In my opinion an actual case of failure in learning a pattern like in the present experiment must not permit the strict conclusion of unlearnability at all.

However, with the help of the present results I definitely argue for a naturalness bias in learning morphophonemic alternations.

In OT, agreement constraints are well-known. They clearly allow the structures and alternations on the basis of vowel harmony. The alternation is simply explained by those agreement constraints that favour the harmonised patterns.

A constraint that favours arbitrary patterns such as in the present case is far more difficult to imagine. Such a constraint would need to connect the sonorancy of the initial consonant to the place of the suffix vowel. As shown, neither phonetics nor phonology provides support for such a constraint. Hence, one can hardly think of a constraint that should favour arbitrary rules. Moreover, a constraint like the *same-feature constraint* prevents an arbitrary pattern to be learned. The constraint would forbid alternation candidates that are a result of the arbitrary the arbitrary rule.

To finally weight both factors, naturalness and probability of occurrence, my results clearly imply that during the first part of the learning process, the factor naturalness determines the acquisition process. A natural pattern is biased by UG principles and therefore learned more easily and faster than an unnatural one. I demonstrated that an influence of probability of occurrence is less important during learning process and comes second. Then there is the tendency for the frequent pattern to be learned more easily and faster than the infrequent one.

6 Future Directions

I want to conclude my work with some ideas about how one could go on in future research. I can think of several ways to tie in with the present findings. I will summarise some ideas in the following list but it does not contain any claim to completeness.

- My results do not prove an effect of probability of occurrence. However, I found a tendency for a better learning of frequently presented natural rules rather than infrequently presented natural rules. One future direction could be to confirm what the tendency already suggests.

- The rule of vowel harmony and the arbitrary rule were very different in the present experiment. The harmony process described a dependency between two vowels whereas the arbitrary rule affected a dependency between a vowel and a consonant. Future research could investigate more similar, but still natural and unnatural rules, such as consonant harmony and arbitrary rules (affecting consonants).

- The rule of vowel harmony in my experiment is a highly accepted natural rule for the reasons summarised in section 2.2.1.3. The arbitrary rule is a very unnatural as one could hardly think of such a rule appearing in the world's languages. Future research could deal with how important different characteristics of natural rules are. One could compare them directly by manipulating them in artificial languages. The characteristics could be weighted according to their importance for naturalness.

- The present experiment investigated the behaviour of adults. In future research one could test children and whether they favour a natural rule and a frequently occurring rule to the same amount as adults do.

- Another interesting line of research is the acquisition of the exceptions of alternations. The idea of storage of individual patterns seems not to provide an exhaustive account as there are many exceptions in the world's languages and pure storage would not provide an economic system. Recent research suggests that even exceptions – so unnatural alternation patterns – seem to be productive in some way.

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8 Appendices

Appendix A: Items λ1 and λ2 singular forms

mɪt	met	mœt	mot	mɔt	mʊt
mɪs	mes	mœs	mos	mɔs	mʊs
mɪʃ	meʃ	mœʃ	moʃ	mɔʃ	mʊʃ
mɪp	mep	mœp	mop	mɔp	mʊp
mɪŋ	-	mœŋ	-	mɔŋ	mʊŋ
nɪt	net	nœt	not	nɔt	nʊt
nɪs	nes	nœs	nos	nɔs	nʊs
nɪʃ	neʃ	nœʃ	noʃ	nɔʃ	nʊʃ
nɪp	nep	nœp	nop	nɔp	nʊp
nɪŋ	-	nœŋ	-	nɔŋ	nʊŋ
jɪt	jet	jœt	jot	jɔt	jʊt
jɪs	jes	jœs	jos	jɔs	jʊs
jɪʃ	jeʃ	jœʃ	joʃ	jɔʃ	jʊʃ
jɪp	jep	jœp	jop	jɔp	jʊp
jɪŋ	-	jœŋ	-	jɔŋ	jʊŋ
lɪt	let	lœt	lot	lɔt	lʊt
lɪs	les	lœs	los	lɔs	lʊs
lɪʃ	leʃ	lœʃ	loʃ	lɔʃ	lʊʃ
lɪp	lep	lœp	lop	lɔp	lʊp
lɪŋ	-	lœŋ	-	lɔŋ	lʊŋ
fɪt	fet	fœt	fot	fɔt	fʊt
fɪs	fes	fœs	fos	fɔs	fʊs
fɪʃ	feʃ	fœʃ	foʃ	fɔʃ	fʊʃ
fɪp	fep	fœp	fop	fɔp	fʊp
fɪŋ	-	fœŋ	-	fɔŋ	fʊŋ
dɪt	det	dœt	dot	dɔt	dʊt
dɪs	des	dœs	dos	dɔs	dʊs
dɪʃ	deʃ	dœʃ	doʃ	dɔʃ	dʊʃ
dɪp	dep	dœp	dop	dɔp	dʊp
dɪŋ	-	dœŋ	-	dɔŋ	dʊŋ
kɪt	ket	kœt	kot	kɔt	kʊt
kɪs	kes	kœs	kos	kɔs	kʊs
kɪʃ	keʃ	kœʃ	koʃ	kɔʃ	kʊʃ
kɪp	kep	kœp	kop	kɔp	kʊp
kɪŋ	-	kœŋ	-	kɔŋ	kʊŋ
zɪt	zet	zœt	zot	zɔt	zʊt
zɪs	zes	zœs	zos	zɔs	zʊs
zɪʃ	zeʃ	zœʃ	zoʃ	zɔʃ	zʊʃ
zɪp	zep	zœp	zop	zɔp	zʊp
zɪŋ	-	zœŋ	-	zɔŋ	zʊŋ

Appendix B: Items λ1 plural forms

trigger	ɪ [front]	e [front]	œ [front]	o [back]	Ɔ [back]	ʊ [back]
	mɪty	mety	mœty	motu	mƆtu	mʊtu
	mɪsy	mesy	mœsy	mosu	mƆsu	mʊsu
	mɪʃy	meʃy	mœʃy	moʃu	mƆʃu	mʊʃu
	mɪpy	mepy	mœpy	mopu	mƆpu	mʊpu
	mɪŋy	-	mœŋy	-	mƆŋu	mʊŋu
	nɪty	nety	nœty	notu	nƆtu	nʊtu
	nɪsy	nesy	nœsy	nosu	nƆsu	nʊsu
	nɪʃy	neʃy	nœʃy	noʃu	nƆʃu	nʊʃu
	nɪpy	nepy	nœpy	nopu	nƆpu	nʊpu
	nɪŋy	-	nœŋy	-	nƆŋu	nʊŋu
	jɪty	jety	jœty	jotu	jƆtu	jʊtu
	jɪsy	jesy	jœsy	josu	jƆsu	jʊsu
	jɪʃy	jeʃy	jœʃy	joʃu	jƆʃu	jʊʃu
	jɪpy	jepy	jœpy	jopu	jƆpu	jʊpu
	jɪŋy	-	jœŋy	-	jƆŋu	jʊŋu
	lɪty	lety	lœty	lotu	lƆtu	lʊtu
	lɪsy	lesy	lœsy	losu	lƆsu	lʊsu
	lɪʃy	leʃy	lœʃy	loʃu	lƆʃu	lʊʃu
	lɪpy	lepy	lœpy	lopu	lƆpu	lʊpu
	lɪŋy	-	lœŋy	-	lƆŋu	lʊŋu
	fɪty	fety	fœty	fotu	fƆtu	fʊtu
	fɪsy	fesy	fœsy	fosu	fƆsu	fʊsu
	fɪʃy	feʃy	fœʃy	foʃu	fƆʃu	fʊʃu
	fɪpy	fepy	fœpy	fopu	fƆpu	fʊpu
	fɪŋy	-	fœŋy	-	fƆŋu	fʊŋu
	dɪty	dety	dœty	dotu	dƆtu	dʊtu
	dɪsy	desy	dœsy	dosu	dƆsu	dʊsu
	dɪʃy	deʃy	dœʃy	doʃu	dƆʃu	dʊʃu
	dɪpy	depy	dœpy	dopu	dƆpu	dʊpu
	dɪŋy	deŋy	dœŋy	doŋu	dƆŋu	dʊŋu
	kɪty	kety	kœty	kotu	kƆtu	kʊtu
	kɪsy	kesy	kœsy	kosu	kƆsu	kʊsu
	kɪʃy	keʃy	kœʃy	koʃu	kƆʃu	kʊʃu
	kɪpy	kepy	kœpy	kopu	kƆpu	kʊpu
	kɪŋy	-	kœŋy	-	kƆŋu	kʊŋu
	zɪty	zety	zœty	zotu	zƆtu	zʊtu
	zɪsy	zesy	zœsy	zosu	zƆsu	zʊsu
	zɪʃy	zeʃy	zœʃy	zoʃu	zƆʃu	zʊʃu
	zɪpy	zepy	zœpy	zopu	zƆpu	zʊpu
	zɪŋy	-	zœŋy	-	zƆŋu	zʊŋu

Appendix C: Items λ2 plural forms

trigger						
m	mɪty	mety	mœty	moty	mƆty	mʊty
[+son]	mɪsy	mesy	mœsy	mosy	mƆsy	mʊsy
	mɪʃy	meʃy	mœʃy	moʃy	mƆʃy	mʊʃy
	mɪpy	mepy	mœpy	mopy	mƆpy	mʊpy
	mɪŋy	-	mœŋy	-	mƆŋy	mʊŋy
n [+son]	nɪty	nety	nœty	noty	nƆty	nʊty
	nɪsy	nesy	nœsy	nosy	nƆsy	nʊsy
	nɪʃy	neʃy	nœʃy	noʃy	nƆʃy	nʊʃy
	nɪpy	nepy	nœpy	nopy	nƆpy	nʊpy
	nɪŋy	-	nœŋy	-	nƆŋy	nʊŋy
j	jɪty	jety	jœty	joty	jƆty	jʊty
[+son]	jɪsy	jesy	jœsy	josy	jƆsy	jʊsy
	jɪʃy	jeʃy	jœʃy	joʃy	jƆʃy	jʊʃy
	jɪpy	jepy	jœpy	jopy	jƆpy	jʊpy
	jɪŋy	-	jœŋy	-	jƆŋy	jʊŋy
l	lɪty	lety	lœty	loty	lƆty	lʊty
[+son]	lɪsy	lesy	lœsy	losy	lƆsy	lʊsy
	lɪʃy	leʃy	lœʃy	loʃy	lƆʃy	lʊʃy
	lɪpy	lepy	lœpy	lopy	lƆpy	lʊpy
	lɪŋy	-	lœŋy	-	lƆŋy	lʊŋy
f	fɪtu	fetu	fœtu	fotu	fƆtu	fʊtu
[-son]	fɪsu	fesu	fœsu	fosu	fƆsu	fʊsu
	fɪʃu	feʃu	fœʃu	foʃu	fƆʃu	fʊʃu
	fɪpu	fepu	fœpu	fopu	fƆpu	fʊpu
	fɪŋu	-	fœŋu	-	fƆŋu	fʊŋu
d	dɪtu	detu	dœtu	dotu	dƆtu	dʊtu
[-son]	dɪsu	desu	dœsu	dosu	dƆsu	dʊsu
	dɪʃu	deʃu	dœʃu	doʃu	dƆʃu	dʊʃu
	dɪpu	depu	dœpu	dopu	dƆpu	dʊpu
	dɪŋu	-	dœŋu	-	dƆŋu	dʊŋu
k	kɪtu	ketu	kœtu	kotu	kƆtu	kʊtu
[-son]	kɪsu	kesu	kœsu	kosu	kƆsu	kʊsu
	kɪʃu	keʃu	kœʃu	koʃu	kƆʃu	kʊʃu
	kɪpu	kepu	kœpu	kopu	kƆpu	kʊpu
	kɪŋu	-	kœŋu	-	kƆŋu	kʊŋu
z	zɪtu	zetu	zœtu	zotu	zƆtu	zʊtu
[-son]	zɪsu	zesu	zœsu	zosu	zƆsu	zʊsu
	zɪʃu	zeʃu	zœʃu	zoʃu	zƆʃu	zʊʃu
	zɪpu	zepu	zœpu	zopu	zƆpu	zʊpu
	zɪŋu	-	zœŋu	-	zƆŋu	zʊŋu

Appendix D: λ1 and λ2 singular forms – picture assignment (part 1)

item	pict.	item	pict.	item	pict.
mɪt	ostrich	met	raccoon	mœt	barn
mɪs	lemon	mes	flag	mœs	wrench
mɪʃ	sweater	meʃ	pipe	mœʃ	arrow
mɪp	artichoke	mep	screwdriver	mœp	deer
mɪŋ	pliers	-	-	mœŋ	rocking chair
nɪt	record player	net	clown	nœt	finger
nɪs	mitten	nes	potato	nœs	pocketbook
nɪʃ	sock	neʃ	squirrel	nœʃ	needle
nɪp	stove	nep	lettuce	nœp	doorknob
nɪŋ	shirt	-	-	nœŋ	sun
jɪt	moon	jet	foot	jœt	drum
jɪs	blouse	jes	key	jœs	butterfly
jɪʃ	watch	jeʃ	grapes	jœʃ	banana
jɪp	well	jep	fly	jœp	iron
jɪŋ	doll	-	-	jœŋ	pants
lɪt	rhinoceros	let	zebra	lœt	brush
lɪs	coat	les	nose	lœs	bear
lɪʃ	bird	leʃ	pencil	lœʃ	peach
lɪp	thimble	lep	cherry	lœp	leaf
lɪŋ	ear	-	-	lœŋ	cannon
fɪt	crown	fet	goat	fœt	baseball bat
fɪs	monkey	fes	tomato	fœs	hammer
fɪʃ	horse	feʃ	pot	fœʃ	church
fɪp	car	fep	dresser	fœp	nut
fɪŋ	kettle	-	-	fœŋ	accordion
dɪt	necklace	det	celery	dœt	baby carriage
dɪs	kangaroo	des	wineglass	dœs	sailboat
dɪʃ	motorcycle	deʃ	hand	dœʃ	duck
dɪp	grasshopper	dep	saw	dœp	spool of thread
dɪŋ	glove	-	-	dœŋ	ant
kɪt	cigar	ket	fox	kœt	clothespin
kɪs	gun	kes	lips	kœs	lock
kɪʃ	cake	keʃ	eagle	kœʃ	airplane
kɪp	nail file	kep	beetle	kœp	pitcher
kɪŋ	garbage can	-	-	kœŋ	clock
zɪt	screw	zet	football	zœt	snake
zɪs	fence	zes	pen	zœs	cigarette
zɪʃ	chisel	zeʃ	window	zœʃ	toe
zɪp	asparagus	zep	pineapple	zœp	bowl
zɪŋ	bell	-	-	zœŋ	cup

Appendix E: λ1 and λ2 singular forms – picture assignment (part 2)

item	pict.	item	pict.	item	pict.
mot	sandwich	mɔt	turtle	mʊt	corn
mos	hat	mɔs	barrel	mʊs	carrot
moʃ	tie	mɔʃ	mountain	mʊʃ	peacock
mop	cow	mɔp	kite	mʊp	belt
-	-	mɔŋ	pig	mʊŋ	door
not	broom	nɔt	rooster	nʊt	elephant
nos	trumpet	nɔs	piano	nʊs	plug
noʃ	light buld	nɔʃ	hanger	nʊʃ	orange
nop	gorilla	nɔp	traffic light	nʊp	tennis racket
-	-	nɔŋ	sled	nʊŋ	onion
jot	couch	jɔt	whistle	jʊt	swing
jos	mouse	jɔs	flower	jʊs	ball
joʃ	wheel	jɔʃ	bed	jʊʃ	snowman
jop	guitar	jɔp	light switch	jʊp	paintbrush
-	-	jɔŋ	lobster	jʊŋ	glasses
lot	peanut	lɔt	arm	lʊt	refridgerator
los	violin	lɔs	skunk	lʊs	chicken
loʃ	owl	lɔʃ	mushroom	lʊʃ	ladder
lop	pear	lɔp	rabbit	lʊp	chain
-	-	lɔŋ	dress	lʊŋ	lamp
fot	apple	fɔt	watering can	fʊt	hair
fos	top	fɔs	rolling pin	fʊs	French horn
foʃ	giraffe	fɔʃ	leopard	fʊʃ	sheep
fop	table	fɔp	wagon	fʊp	sea horse
-	-	fɔŋ	anchor	fʊŋ	comb
dot	pumpkin	dɔt	vest	dʊt	bicycle
dos	tree	dɔs	heart	dʊs	fork
doʃ	book	dɔʃ	envelope	dʊʃ	truck
dop	ironing board	dɔp	frog	dʊp	cloud
-	-	dɔŋ	toaster	dʊŋ	lion
kot	pepper	kɔt	bow	kʊt	box
kos	bread	kɔs	cap	kʊs	fish
koʃ	thumb	kɔʃ	donkey	kʊʃ	roller skate
kop	caterpillar	kɔp	train	kʊp	gun
-	-	kɔŋ	balloon	kʊŋ	basket
zot	bee	zɔt	helicopter	zʊt	chair
zos	spoon	zɔs	scissors	zʊs	stool
zoʃ	boot	zɔʃ	windmill	zʊʃ	flute
zop	spider	zɔp	suitcase	zʊp	harp
-	-	zɔŋ	alligator	zʊŋ	leg

Appendix F: Individual results

Group	Number of participant	Performances	
		Accuracy	Percent correct
NF (natural/frequent)	NF 1	47	49.0
	NF 2	42	43.8
	NF 3	94	97.9
	NF 4	92	95.8
	NF 5	95	99.0
	NF 6	94	97.9
	NF 7	96	100
	NF 8	96	100
	NF 9	61	63.5
	NF 10	72	75.0
	NF 11	62	64.6
	NF 12	54	56.3
	NF 13	66	68.8
	NF 14	50	52.1
	NF 15	53	55.2
	NF 16	63	65.6
	NF 17	95	99.0
	NF 18	95	99.0
	NF 19	96	100
	NF 20	58	60.4
NI (natural/infrequent)	NI 1	47	49.0
	NI 2	50	52.1
	NI 3	92	95.8
	NI 4	73	76.0
	NI 5	79	82.3
	NI 6	58	60.4
	NI 7	53	55.2
	NI 8	53	55.2
	NI 9	53	55.2
	NI 10	96	100
	NI 11	79	82.3
	NI 12	51	53.1
	NI 13	54	56.3
	NI 14	69	71.9
	NI 15	46	47.9
	NI 16	36	37.5
	NI 17	96	100
	NI 18	65	67.7
	NI 19	96	100
	NI 20	80	83.3
UF (unnatural/frequent)	UF 1	47	49.0
	UF 2	44	45.8
	UF 3	49	51.0
	UF 4	52	54.2
	UF 5	50	52.1

	UF 6	47	49.0
	UF 7	48	50.0
	UF 8	45	46.9
	UF 9	48	50.0
	UF 10	51	53.1
	UF 11	50	52.1
	UF 12	50	52.1
	UF 13	48	50.0
	UF 14	53	55.2
	UF 15	44	45.8
	UF 16	49	51.0
	UF 17	53	55.2
	UF 18	43	44.8
	UF 19	52	54.2
	UF 20	46	47.9
UI (unnatural/infrequent)	UI 1	49	51.0
	UI 2	47	49.0
	UI 3	54	56.3
	UI 4	45	46.9
	UI 5	43	44.8
	UI 6	49	51.0
	UI 7	47	49.0
	UI 8	52	54.2
	UI 9	47	49.0
	UI 10	54	56.3
	UI 11	54	56.3
	UI 12	48	50.0
	UI 13	48	50.0
	UI 14	52	54.2
	UI 15	49	51.0
	UI 16	51	53.1
	UI 17	46	47.9
	UI 18	47	49.0
	UI 19	38	39.6
	UI 20	51	53.1

Appendix G: Participants' Characteristics

participant	age	sex	handedness	education
NF1_01	21	male	right	A-level
NF1_02	19	female	right	A-level
NF1_03	27	male	right	Bachelor
NF1_04	48	female	right	master's degree
NF1_05	24	female	right	A-level
NF1_06	20	female	right	A-level
NF1_07	25	female	right	A-level
NF1_08	20	female	right	A-level
NF1_09	35	female	right	master's degree
NF1_10	21	female	right	A-level
NF2_01	20	female	right	A-level
NF2_02	19	female	right	A-level
NF2_03	20	female	right	A-level
NF2_04	23	male	right	master's degree
NF2_05	21	female	right	A-level
NF2_06	21	female	right	A-level
NF2_07	20	female	right	A-level
NF2_08	21	female	right	A-level
NF2_09	19	female	right	A-level
NF2_10	20	female	right	A-level
NI1_01	19	female	right	A-level
NI1_02	27	female	right	A-level
NI1_03	20	female	right	A-level
NI1_04	21	female	right	A-level
NI1_05	19	female	right	A-level
NI1_06	19	female	right	A-level
NI1_07	20	female	both	A-level
NI1_08	21	female	right	A-level
NI1_09	21	female	right	A-level
NI1_10	50	male	right	doctor's degree
NI2_01	22	male	left	A-level
NI2_02	20	male	right	A-level
NI2_03	19	female	right	A-level
NI2_04	19	female	right	A-level
NI2_05	21	male	right	A-level
NI2_06	21	female	right	A-level
NI2_07	21	female	right	A-level
NI2_08	21	female	right	A-level
NI2_09	20	female	right	A-level
NI2_10	25	female	right	A-level
UF1_01	21	female	right	A-level
UF1_02	21	female	right	A-level
UF1_03	20	female	right	A-level
UF1_04	23	male	right	A-level
UF1_05	27	male	right	master's degree

UF1_06	20	female	right	A-level
UF1_07	28	male	right	A-level
UF1_08	20	female	right	A-level
UF1_09	20	female	right	A-level
UF1_10	25	male	right	A-level
UF2_01	26	female	left	master's degree
UF2_02	21	female	right	A-level
UF2_03	20	female	right	A-level
UF2_04	19	female	right	A-level
UF2_05	35	male	right	A-level
UF2_06	19	female	right	A-level
UF2_07	22	female	right	A-level
UF2_08	20	female	right	A-level
UF2_09	25	female	right	A-level
UF2_10	24	female	right	Bachelor
UI1_01	27	male	right	A-level
UI1_02	23	female	right	Bachelor
UI1_03	28	female	right	A-level
UI1_04	20	female	right	A-level
UI1_05	21	female	right	A-level
UI1_06	20	female	right	A-level
UI1_07	19	female	right	A-level
UI1_08	20	female	right	A-level
UI1_09	21	female	right	A-level
UI1_10	26	male	right	master's degree
UI2_01	43	male	right	secondary education certificate
UI2_02	28	female	right	A-level
UI2_03	22	female	right	A-level
UI2_04	21	female	right	A-level
UI2_05	21	male	right	A-level
UI2_06	20	female	right	A-level
UI2_07	19	female	right	A-level
UI2_08	21	male	right	A-level
UI2_09	19	female	right	A-level
UI2_10	18	male	both	secondary education certificate
total		62 female 18 male	76 right-handed 2 left-handed 2 ambidextrous	2 secondary education certificate 68 A-level 3 Bachelor 6 master's degree 1 doctor's degree

Appendix H: Assertion of autonomous writing

Versicherung der selbständigen Abfassung

Hiermit versichere ich, die vorliegende Arbeit selbständig verfasst sowie keine anderen Quellen und Hilfsmittel als die angegebenen benutzt zu haben.

Datum Unterschrift

Appendix I: German summary

Suffixe, die an Wortstämme angehängt werden, tragen grammatische Informationen. Bei Verben wird dabei die Person, Numerus, Tempus, Modus und Genus Verbi angezeigt, bei Nomen Kasus, Numerus und Genus. Durch phonologische Kontexte bedingt kann eine solche morphologische Markierung ihre Gestalt ändern und unterschiedliche Oberflächenformen annehmen. Die dabei entstandenen Allomorphe werden durch regelbasierte Prozesse von dem zugrunde liegenden Morphem abgeleitet. Es zeigt sich, dass der Erwerb morphophonemischer Alternationen ein aufwendiger und schwieriger Lernprozess ist.

Die vorliegende Arbeit beschäftigt sich nun mit Faktoren, die den Erwerb der Alternationen positiv beeinflussen können. Zum einen wird der Faktor Natürlichkeit, zum anderen der Faktor Auftretenshäufigkeit diskutiert.

Trotz einiger widersprüchlicher Evidenzen bezüglich des ersten Faktors hat sich in der neueren Forschung herausgestellt, dass ein natürlicher Prozess leichter zu lernen ist als ein unnatürlicher. Oft konnte ein Vorteil der natürlichen gegenüber den unnatürlichen Prozessen festgestellt werden. Allerdings zeigt sich dieser Umstand nicht immer – dann wiederum zeigt sich kein Vorteil gegenüber einem der beiden Prozesse. Die Ursachen dafür sind in der Methode oder der Herangehensweise zu suchen. Mache Methode scheint nicht sensitiv genug zu sein, den Vorteil aufzudecken, und manche Studien gehen unterschiedlich an die generelle Frage heran, was denn überhaupt ein *natürlicher* Prozess ist. Unter Berücksichtigung der einschlägigen Literatur habe ich Charakteristika eines typisch natürlichen Prozesses herausgearbeitet und damit die definitorische Grundlage für die empirische Untersuchung derselben bestimmt.

Die Auftretenshäufigkeit eines Prozesses scheint auch ein entscheidender Faktor für den Erwerbsprozess zu sein. Dabei wird der Prozess leichter gelernt, der frequent im Input vorliegt, wohingegen ein Prozess schwieriger zu lernen ist, je weniger häufig er vorkommt. In verschiedenen Studien konnte gezeigt werden, dass die bloße Verteilung eines Musters in Wörtern bzw. im Lexikon schon ausreichen kann, zugrunde liegende Repräsentationen zu formen. Dabei ist immer das frequentere Muster das zuverlässigere.

Anhand einer experimentellen Studie habe ich beide Faktoren direkt miteinander verglichen. Es wurde die Lernbarkeit einer natürlichen künstlichen Sprache mit der einer unnatürlichen künstlichen Sprache verglichen. Die Sprachen unterschieden sich lediglich in der Regel, nach der eines von zwei Pluralmorphemen ausgewählt werden musste, wobei die natürliche Sprache nach Vokalharmonie alternierte und die unnatürliche Sprache nach einer arbiträren Regel. In zwei Hauptgruppen wurde 80 erwachsenen Deutschen entweder die eine oder die andere Sprache präsentiert. In jeder Gruppe wurde die Hälfte der Probanden häufig (zu 50%) mit der Alternation konfrontiert, die andere Hälfte infrequent (zu 25%). Nach der Familiarisierungsphase ohne expliziten Lernauftrag war die Aufgabe aller Probanden, von neuen Wörtern der Sprache(n) den Plural zu bilden.

Die Analyse der Reaktionen ergab einen Effekt der Natürlichkeit, aber keinen der Auftretenshäufigkeit: Die natürliche Sprache war deutlich besser zu lernen als die unnatürliche. Die Auftretenshäufigkeit in beiden Sprachen führte zu keinem signifikanten Unterschied. Kein einziger von den 40 Probanden, die die unnatürliche Regel präsentiert bekamen, hat die Regel für die entsprechende Alternation gelernt. Es zeigt sich jedoch eine Tendenz bei den Probanden, die die natürliche Sprache erlernen sollten: Diejenigen scheinen einen Vorteil zu haben, die häufiger die Alternation während der Familiarisierungsphase hören. Aber auch unter den Probanden, die mit der natürlichen Sprache konfrontiert wurden, zeigten einige gar keinen Lernerfolg, weshalb ich vermute, dass wegen der großen Varianz in den Daten die Auftretenshäufigkeit als einflussreicher Faktor empirisch nicht belegt werden konnte.

Zusammenfassend konnte nachgewiesen werden, dass das Lernen der Alternationen sehr stark von einem *bias* für Natürlichkeit beeinflusst wird. Allein mit der distributionellen Analyse der verschiedenen Pluralendungen hätte der Vorteil für die Alternation der natürlichen Sprache nicht erklärt werden können.