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The Interaction of Language-Specific and Universal Factors During the Acquisition of Morphophonemic Alternations With Exceptions

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Abstract

Using the artificial language paradigm, we studied the acquisition of morphophonemic alternations with exceptions by 160 German adult learners. We tested the acquisition of two types of alternations in two regularity conditions while additionally varying length of training. In the first alternation, a vowel harmony, backness of the stem vowel determines backness of the suffix. This process is grounded in substance (phonetic motivation), and this universal phonetic factor bolsters learning a generalization. In the second alternation, tenseness of the stem vowel determines backness of the suffix vowel. This process is not based in substance, but it reflects a phonotactic property of German and our participants benefit from this language-specific factor. We found that learners use both cues, while substantive bias surfaces mainly in the most unstable situation. We show that language-specific and universal factors interact in learning.

Keywords: Phonology; Exceptional alternation; Acquisition; Substance; Phonotactics; Artificial language paradigm

1. Introduction

Learning a language is one of the core challenges for human cognition. Countless linguistic rules need to be learned, and regardless of the linguistic domain, learners may face difficulties, as many rules are inconsistently applied (Chomsky & Halle, 1968; Gouskova, 2012; Pater, 2004, 2007; Zonneveld, 1978, 1980; Zuraw, 2000). The factors that govern the process of irregular pattern learning are far from being understood. In this

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study we look at the process learning alternations in more detail and consider what properties support their acquisition. We focus on the acquisition of morphophonological patterns. Morphemes that change their shape depending on the context are said to alternate. Often they alternate to make a form agree with the phonotactics of the language (Zsiga, 2013), so learners are faced with a difficult task: They need to know phonotactics and morphology in advance to be able to cope with alternations. It is known that competent speakers are then able to generalize patterns to new words. Research in acquisition to date has focused on phonological patterns that are perfectly predictable. When it comes to irregular patterns, many studies in the literature have focused on the acquisition of morphology. We only mention two well-known examples: research on the acquisition of the English past tense (Berko-Gleason, 1958; Rumelhart & McClelland, 1986) and of German plurals (Clahsen, 1999; Köpcke, 1998). Recent research discusses various factors that influence both the acquisition process and the generalization behavior, such as frequency of occurrence, locality, knowledge about abstract features, and substance (Baer-Henney & van de Vijver, 2012; Cristià & Seidl, 2008; Hayes & White, 2013; Newport & Aslin, 2004; Wilson, 2006). Acquisition studies mostly rely on data based on populations that have a certain language experience. These can be children, who are already equipped with at least some knowledge of their native language, or, of course, adults. In the acquisition studies language-specific characteristics have mostly been disregarded, and we believe their possible influential power in the acquisition of new patterns has not yet been adequately considered.

In our study we investigate the acquisition of irregular phonological patterns that determine the pronunciation of a morphological suffix. More specifically, we focus on two factors. Our aim is to investigate the extent of the influence of grounding in phonetic substance as a universal factor and L1 phonotactics as a language-specific factor in the acquisition of morphophonological alternations.

In the introduction we will first give an overview of the occurrence of irregular alternations in the world's languages to prove their existence and therefore highlight the need to study their acquisition. We then summarize the research that deals with the factor of substance during the acquisition of morphophonemic alternations and investigates its influence on the acquisition process. After that we show that generalization behavior in adults seems to be influenced by this factor as well. In addition we argue that language-specific factors may also play a role before continuing on to the experimental investigation.

Many alternants can be predicted by phonological rules, but there are alternations that are not predictable, and we will now give examples to show that this happens quite often. For example, there is the voicing alternation in German nouns (Wiese, 1996). A final voiceless obstruent may become voiced if a plural suffix is added to the word —[bɛɐk] ~ [bɛɐg-ə] (*mountain* ~ *mountain-PL*). In another case the voiceless obstruent remains voiceless as in [vɛɐk] ~ [vɛɐk-ə] (*work* ~ *work-PL*). A similar exceptional voicing alternation is found in English, where labial fricatives [f/θ] alternate with their voiced counterparts [v/ð] in some cases of the singular ~ plural paradigm, but not in all —[naɪf] ~ [naɪvz], but [stɪf] ~ [stɪfs] (Becker, Nevins, & Levine, 2012). Irregular alternations concern vowels, too. In German singular ~ plural formation and in other morphological contexts such as diminutives, some vowels become front and others do not. The alternation is a remnant of a former vowel harmony (Klein, 2000). In Hungarian vowel harmony front and back suffixes conform to stem vowels—[y]st-n[ɛ]k (*cauldron-DAT)*, [ɔ]bl[ɔ]k-n[ɔ]k (*window-DAT)*, but there are neutral vowels that come with either suffix—c[iː]m-n[ɛ]k (*address- DAT)*, s[iː]p-n[ɔ]k (*whistle-DAT)* (Hayes, Zuraw, Siptár, & Londe, 2009) or even disharmonic forms (Phelps, 1978). Turkish has harmonic polysyllabic roots which conform to several vowel harmony patterns, but still under certain circumstances there are disharmonic forms—s[a]t-[i] (*watch.DEF-ACC*), f-[e]vk-[ɨ] (*top.DEF-ACC*) (Clements & Sezer, 1982). More examples of alternations with exceptions can be found in Turkish (Becker, Ketrez, & Nevins, 2011), where there is an irregular voicing alternation, and in Brazilian Portuguese (Gomes & Manoel, 2010), where there is an irregular glide alternation ([w] ~ [j]). Other examples of harmony patterns with exceptions can be found in Finnish (Ringen & Heinämäki, 1999) and Mongolian (LaCross, 2011). In short, many alternations come with exceptions; it happens in many of the world's languages and across language families. Irregularity affects all kinds of patterns, those involving consonants as well as vowels. However, not much research has addressed the question of how they would be acquired and, more specifically, the issue of the division of labor between substantive and language-specific factors in learning alternations with exceptions.

1.1. Substance in acquisition

There is a growing body of literature that shows that there is a learning advantage for substantively based patterns—that is, patterns that facilitate either perception or production—in particular, patterns that involve natural classes rather than arbitrary groupings of sounds. An alternation can be grounded in phonetics to different degrees; it can facilitate perception and/or production to a greater or a lesser extent. Research has focused on studies in which the process of acquisition of regularities in natural languages has been observed over time, beginning with infants during their first year of life (Fikkert & Freitas, 2006) up to children at the age of around 8 years (Berko-Gleason, 1958; Flege, 1982; Kerkhoff, 2007; van de Vijver & Baer-Henney, 2012b). These studies are complemented by an increasing amount of research in which children (Cristià & Peperkamp, 2012; Cristià & Seidl, 2008; Cristià, Seidl, & Gerken, 2011; Seidl & Buckley, 2005) or adults (Baer-Henney & van de Vijver, 2012; Finley, 2012a; Pycha, Nowak, Shin, & Shosted, 2003; Redford, 2008; Schane, Tranel, & Lane, 1975; Wilson, 2003, 2006) are taught artificial languages which contain new phonological regularities. In these studies populations of different ages starting with children in their first year of life up to the point of adulthood have been investigated and a possible advantageous influence of substance is debated.

Wilson (2006), for instance, argues that substance can act as a bias in acquisition. The idea of the bias is that a pattern that is grounded in substance is learned more easily than a pattern that is not. And a more complicated pattern implies application in less complicated cases. English adults were taught velar palatalization patterns which facilitated production and perception to a greater or a lesser degree. Participants generalized a phonetically more complicated pattern to new, phonetically less complicated forms, but not vice versa. Likewise, Finley (2012b) found an asymmetrical generalization of rounding harmony. Participants who were trained with a rounding harmony of mid vowels extended the harmony to new items, but those who were trained with a rounding harmony of high vowels did not extend it. In this case, ease of perception seems to be responsible for the asymmetry: Roundness is easier to perceive in high vowels than in mid vowels (Kaun, 2004). Redford (2008) showed that ease of production also constrains the acquisition of phonotactics: Onsets with a rise in sonority, which are more strongly coarticulated, are learned more easily than onsets with a sonority plateau, which are less strongly coarticulated. For the case of irregular alternations, van de Vijver and Baer-Henney (2012b) showed in their study with German children of different ages that a substantively based voicing alternation and a phonetically arbitrary vowel alternation follow different acquisition paths. Generalizations of the first alternation decrease with age while generalizations of the latter alternation increase with age. Adult speakers then generalize both alternations to the same extent. Patterns in which natural classes of sounds are involved are learned more easily than patterns that involve groupings of sounds that do not form a particular natural class. This has been shown for children (Cristià & Seidl, 2008) as well as for adults (Baer-Henney & van de Vijver, 2012; Skoruppa & Peperkamp, 2011).

However, the discussion also includes dissenting opinions that argue against the facilitating influence of substance. Arbitrary patterns are part of the patterns of the languages of the world and they can be productive (Coetzee, Lin, & Pretorius, 2007; Pierrehumbert, 2006), and, hence, children should be able to learn them; studies with children and adult learners have shown that such patterns are indeed learnable. Seidl and Buckley (2005) reject an advantage of phonetically grounded over phonetically arbitrary patterns; the infants in their experiments were able to distinguish and learn substantively based and arbitrary spirantization and consonant-vowel assimilation patterns to the same extent. While their results do not necessarily support the equal treatment of substantively based and arbitrary patterns during acquisition, they show that children can cope with arbitrary patterns quite well. In the study of Cristià et al. (2011) infants as young as 4 months old grouped not only sounds of one natural class together but also more dissimilar sounds. Hence, detecting the advantage can be problematic.

In fact, experiments such as the ones described involve very short exposure phases (as compared to natural language learning). If presented with more input of a particular pattern, a learner might reach a ceiling effect in many cases. Baer-Henney and van de Vijver (2012) demonstrate this crucial role of frequency of occurrence by showing that alternations are acquired more readily if presented at a higher frequency of occurrence.

As shown in this section, the contribution of substance to the acquisition of phonological patterns is disputed and experimenters are faced with the difficulty that investigating the influence of substance in an acquisition study can be hard in the light of other possible interferences. Still we believe that research has shown that substance can act as a bias rather than an absolute restriction in that patterns that are substantively based are learned more readily than patterns that are not. We will now discuss how substance also influences generalization behavior.

1.2. Substance in generalizations

The role of substance is not only discussed for learning but also in studies that investigate how speakers generalize particular patterns of their language to novel items. In these studies it is shown how a substantive bias influences the generalization of trends in the lexicon, where a trend is understood as a pattern that is not always true. Speakers are assumed to be equipped with certain linguistic knowledge. Such studies investigate which of the patterns known to a speaker are generalized to new items and which ones are not. Adult speakers then show that they are aware of the distribution of irregular morphophonological trends in the lexicon. In a number of studies they have been asked to extend morphophonological modifications to novel items; in these tasks adults mirror the distribution of morphophonological trends in their native lexicon quite accurately (Albright & Hayes, 2003; Ernestus & Baayen, 2003; van de Vijver & Baer-Henney, 2012a). Ernestus and Baayen (2003), for instance, demonstrate that Dutch speakers generalize the Dutch voicing alternation proportionally to the distribution of this alternation in the lexicon, as do German adults concerning the German voicing and vowel alternation (van de Vijver & Baer-Henney, 2011, 2012b). Speakers rely on what they know about the representations of similar words in their lexicon and transfer this knowledge to the new stimulus material.

Crucially, in recent experiments it has been shown that participants sometimes overestimate the proportion of an alternation in their lexicon, and sometimes they underestimate it. A speaker disproportionately uses a pattern compared to its distribution in the lexicon. While in the lexicon a pattern might be reliable to the extent of 60%, a speaker might realize it in 90% of the new items or in only 20% of the new items. These systematically deviant estimates have been taken as evidence that factors other than lexical ones play a role in generalizations, for example, substance. A substantively based mechanism would then push the application of substantively based patterns while it would prevent the application of patterns which are not substantively biased. Hence, substance appears to be an accurate predictor of over- and undergeneralizations.

A body of literature shows that like in acquisition, substance can act as a bias in generalizations. The findings of some recent representative studies show that speakers are biased in their generalizations; their generalizations are biased toward substantively motivated ones. Hayes et al. (2009) demonstrated that the Hungarian lexicon displays several patterns, some of which are reproduced by Hungarian adult speakers but generalized at a significantly lower rate than what would be expected from the lexicon. These patterns concern the predominant tendency to prefer front suffixes when the stems ends in two consonants or in a bilabial stop. Similarly, Becker et al. (2011) showed that Turkish adults generalize some but not all patterns that can be found in their native lexicon. They reproduce the distribution of laryngeal alternations in Turkish depending on noun size and the place of articulation of the final obstruent. Both of these dependencies are commonly found in the world's languages. However, the dependency of laryngeal alternations on the quality of the preceding vowel—the voicing of coronal obstruents after high vowels and the voicing of palatals after back vowels—is not generalized to new words. This dependency has no typological support. While the number of syllables and the preceding vowel's place of articulation are known to influence the laryngeal status of a final consonant, vowel height and vowel backness are not known to interact with the laryngeal features. Becker et al. argue that such patterns are beyond the scope of generally possible phonological interactions.

Other related research has investigated infixation patterns in Tagalog (Zuraw, 2007) and the exception-less tone sandhi processes of Mandarin (Zhang & Lai, 2010). Also, studies in language processing have shown that speakers are sensitive to the gradient wellformedness of forms in terms of phonetic constraints even if their language does not contain a distributional bias against patterns that are disfavored for phonetic reasons (Becker & Gouskova, 2013; Becker et al., 2012; Coetzee, 2008; Hayes & White, 2013; Kager & Shatzman, 2007).

From this discussion we may conclude that the substantive basis of a pattern also influences the generalization behavior of irregular patterns in adult speakers. We now turn to acquisition studies and to a probable influence of L1 characteristics on the acquisition of a new pattern, an aspect that has not been looked at systematically so far.

1.3. Language-specific influences in the acquisition of new patterns

Regarding language-specific factors, we believe that one very important factor should be considered that has not yet been taken into account. When testing adults we always need to make sure that the new non-native pattern they are trained with is really unknown to them. Although a pattern might be unknown to the learners, the phonological knowledge that is involved, that is, the natural classes of the involved sounds, might be familiar and of importance in the native phonotactics. Although a pattern may superficially appear not to occur in the language, at the level of natural classes there may be evidence in its favor. For instance, even though there are no words in English that start with [vl], there is quite a lot of support for words that start with [obstruent, liquid] sequences. This may explain why a novel word such as [vlog] is readily acceptable (Daland et al., 2011; van de Vijver & Baer-Henney, 2012a; Zsiga, 2013). In an artificial language paradigm (ALP) experiment of Baer-Henney and van de Vijver (2012) even a phonetically arbitrary pattern was learned. The pattern consisted of a dependency between the tenseness and backness of two vowels. A dependency between these unrelated natural classes clearly lacks a phonetic grounding. However, even though backness is not an important feature in terms of German phonotactics, tenseness is (Wiese, 1996). The results from Seidl and Buckley (2005) also allow an interpretation in which the phonotactics of the learner's native language play a crucial role. While their 9-month-old participants accepted both well-formed and ill-formed new forms of an artificial language, their existing knowledge of their native language English (Jusczyk, 1997) could have allowed them to accept both forms since all test forms conformed to English phonotactics.

To date, most acquisition studies have relied on exceptionless patterns, while a number of generalization studies have investigated patterns with exceptions the speakers were familiar with. There are few studies on the acquisition of inconsistent alternations in real language and they suggest that the unreliable situation of learning an alternation with exceptions makes the acquisition process difficult (Kerkhoff, 2007; van de Vijver & Baer-Henney, 2011, 2012b; Zamuner, Kerkhoff, & Fikkert, 2012). However, there is no acquisition study about irregular patterns of an artificial language: to our knowledge, no systematic acquisition study using the framework of the ALP has focused on irregular patterns so far. Generalization and acquisition studies benefit from the ALP method since it provides a powerful tool to investigate the grammar's characterization of intuitions and its development. The idea behind the use of an artificial language is to take advantage of the stringent methodological limits of laboratory phonology conditions. The designer of the artificial language can control all linguistic aspects of it—in the present case its phonemes and phonotactics, as well as the phonological rules that are present in the language. We can show whether and to what extent a newly trained pattern is extended to novel items. The constrained context of an artificial language makes it possible to study the acquisition process of linguistic patterns in isolation, in our case a morphophonological trend, without unintentional interference from other (non-)linguistic factors in the environment.

We want to make use of the ALP to investigate the acquisition of irregular morphophonological alternations. In investigating these patterns, our research questions are whether the universal factor of substance operates as a bias and whether it leads to an advantage in learning. In addition, we examine whether the language-specific phonotactics of L1 can boost the acquisition process. How do these factors interact?

2. An experimental investigation of the acquisition of patterns with exceptions

To approach the above-outlined research questions, we exposed adult learners to morphophonological trends in an artificial lexicon. In order to review our first results and to verify our statistical analysis, we repeated the experiment with a longer training phase. We present these two series of experiments in which we taught adult participants: (a) a pattern with exceptions that has no predominant relevance in the phonotactics of native German speakers, but which is substantively motivated, and (b) a pattern that is relevant in the phonotactics of German, but which is not substantively motivated and is thus phonetically arbitrary.

The first alternation is a vowel backness harmony—the backness of the stem vowel determines the backness of the suffix. Vowel harmony is based in substance (Linebaugh, 2008; Ohala, 1994) and is widespread among the world's languages (Nevins, 2010; Walker, 2011, 2012). There are perceptual as well as productive aspects that make vowel backness harmony a phonetically advantageous pattern. Harmony patterns result in a better perception of words: Only one feature needs to be perceived and it is highlighted by spreading to neighboring segments. The more segments that display the feature, the more easily it is perceived (Kaun, 1995; Zsiga, 2013). Harmonies are known to facilitate production as well. Less articulatory effort is necessary to produce vowels that share a feature (Linebaugh, 2008; Ohala, 1994).

Concerning German, there are no phonotactic interactions between front and back vowels; the distribution of front vowels is independent of the distribution of back vowels and has no consequences for syllable structure in German.

The other alternation is an arbitrary vowel alternation in which the tenseness of the stem vowel determines the backness of the suffix. This vowel alternation is phonetically arbitrary and, to our knowledge, is not found in the world's languages. Both backness and tenseness are distinctive features in German—consider minimal pairs like M[oː]re ~ M[øː]re, *swamps* ~ *carrot*, and H[yː]te ~ H[ʏ]te, *hats* ~ *huts*.

Back vowels are distinguished from front vowels in a two-way distinction of tongue position. In back vowels the dorsum is dorsal and in front vowels the dorsum is coronal. Tense vowels are distinguished from lax vowels by tongue position and their length. German tense vowels are also lengthened in stressed syllables, so not only tenseness but also length categorizes this class of vowels. Tenseness is characterized by the tongue's position and articulatory space; in lax vowels the tongue's position is more central and the articulatory space is more open (Hall, 2000).

The tense/lax distinction is phonetically more involved—more salient—than the front/back distinction: While the front/back distinction can be described in terms of segmental cues only, the tense/lax one requires additional temporal cues. The distinction between tense and lax vowels plays an important role in German phonotactics (Féry, 2001; Vennemann, 1988; Wiese, 1996). A well-formed stressed German syllable requires a minimum of one filled coda position and a maximum of two filled coda positions. Usually the length of this vowel occupies one of the coda positions. Hence, usage of tense versus lax vowels has consequences for the syllable structure: While lax vowels only appear in closed syllables, tense vowels also appear in open syllables. Moreover, lax vowels appear in syllables with a complex coda, while tense vowels mostly do not, as for example in [hʊnt] *dog*, [huːt] *hat* or [huːn] *hen*, but not in the illformed *[huːmp]. Only in some cases may tense vowels appear in this context, namely if the last consonant is coronal, and then this consonant is usually analyzed as extrasyllabic (Wiese, 1996). The contexts of the occurrence of tense and lax vowels in German syllables are summarized in Table 1.

Moreover, the distinction between tense and lax vowels also provides grammatical information as it is used in categorization in morphology and phonetics. For instance, the distinction helps to categorize grammatical classes: Ott (2011) found that German native speakers are aware of the generalization that a consonant cluster preceded by a tense vowel is separated by a morpheme boundary, and this grouping is used to distinguish nouns from verbs. She asked German adults to classify pseudowords with a tensed or lax vowel and a complex coda, which could be either an inflected form of a verb (third-person singular) or a simple noun. She found that pseudowords with lax vowels are more likely to be judged as nouns than as verbs. From a phonetic point of view Germans use the tenseness distinction to

Table 1
Phonotactic properties of tense and lax vowels in German

	Appear in CV	Appear in CVC	Appear in CVCC
Tense	+	+	(−)
Lax	−	+	−

identify the voicing status of following obstruents (Kleber, John, & Harrington, 2010). In the German spelling system, the tense/lax distinction and its phonotactic impact are also reflected: a minimal pair like H[yː]te ~ H[ʏ]te is graphemically distinguished by one or two instances of the same consonant (*Hü.te – Hüt.te*). In German primary schools, the usage of single and double consonants based on the tense/lax distinction is an important topic and is explicitly taught from the second year onward. Usually, the informal terms *short* and *long* vowels are used to differentiate between the instances (Schulte-Körne & Mathwig, 2001). In a study by Kügler (2012) the doubling of consonants is explicitly used to elicit tense versus lax instances of the same vowel in pseudowords. In conclusion, tenseness plays an important role for German speakers and this may direct the German adult learner's attention more to a grammatical difference based on a contrast in the tenseness of the vowels than to one based on the backness of the vowels.

2.1. Experiment series 1

The experiments of the first series have a shorter training phase compared to the experiments of the second series.

2.1.1. Method, design, and hypotheses

We used the ALP to directly compare the acquisition behavior of several groups of participants. The training phase of our experiment consisted of a rather natural way of learning language. Just like a language-learning child, our adult participants received positive input only, although the artificial input was limited to singular and plural forms only. They were presented with stimulus material from an artificial language which we designed for the purpose of this experiment. In the test phase we forced participants to produce new items of the artificial language, and this allowed us to measure the pattern's productivity.

As discussed above, there is not much known about the acquisition of irregular patterns and how factors may contribute to the acquisition process. So we tested two types of alternations in two different (ir)regularity conditions. To do this, we investigated the acquisition of a vowel backness harmony (VH) and of an arbitrary vowel dependency (AV) as introduced above and manipulated the degree of their regularity. In one regularity condition, a majority of 85% followed the main type of alternation and the remaining 15% were exceptions, and in the other regularity condition a majority of 65% followed the main type of alternation and the remaining 35% were exceptions.

We combined the two factors of type of alternation (VH vs. AV) and regularity (85% vs. 65%) in four experimental groups: VH-85, AV-85, VH-65, and AV-65. The experimental design is summarized in Table 2.

The predictions for the comparison of the acquisition of the two types of alternations in this unreliable situation are less clear. On the basis of the study of Baer-Henney and van de Vijver (2012), which compares exactly these two types of alternations in an invariable environment, we would expect that the substantively based VH alternation is learned more easily than the phonetically arbitrary AV alternation. The exceptions in the present experiment, however, put learners in a very uncertain situation. To cope with this,

Table 2
Experimental design in experiment series 1 and 2

Experimental groups	VH-85	AV-85	VH-65	AV-65
Type of alternation	VH	AV	VH	AV
Based in substance	+	–	+	–
Relevant to L1 phonotactics	–	+	–	+
Regularity	85	85	65	65
Proportion of majority alternation during training	85%	85%	65%	65%
Proportion of exceptions during training	15%	15%	35%	35%

they might use all kinds of available information, such as their language-specific knowledge of L1 phonotactics. This could lead to a higher success in learning the AV alternation than could be expected in more reliable situations, as were tested in the experiments in Baer-Henney and van de Vijver (2012). Still we expect that learners will rely on the cue of substance at some point, since many studies show that substance can act as a bias (Finley, 2012b; Redford, 2008; Wilson, 2006).

If substance has more influence than L1 phonotactics, we expect the vowel backness harmony to be learned more readily than the arbitrary vowel alternation. Participants of a VH group should apply the learned alternation to a greater degree than participants of an AV group. If L1 phonotactics has more influence than substance, we expect the arbitrary vowel alternation to be learned more readily than the vowel harmony. Participants of an AV group should apply the alternation to a greater degree than participants of a VH group. If the degree of regularity plays a role during the acquisition of alternations with exceptions, we expect that alternations with fewer exceptions will be learned more readily than alternations with more exceptions. Participants of an 85 group should apply the alternation to a greater degree than participants of a 65 group.

2.1.1.1. Design of stimuli: There was a training phase and a test phase in our experiment. In the first phase participants were trained with one set of items that followed a certain pattern, and in the second phase they were tested with a different set of items in order to find out to what extent they might have learned the pattern and whether they know how to apply it. We avoided measuring memorization effects by not using the same set of items for both phases (Pierrehumbert, 2006).

Our artificial lexicon contained singular and plural nouns. Each auditory stimulus was accompanied by a gray-scaled picture of an object from the Snodgrass and Vanderwart (1980) collection which had been randomly assigned to a singular item (Rossion & Pourtois, 2004). For plural forms, a picture of two of the assigned objects accompanied the auditory stimulus.

The singular form was always a simple CVC stem and the plural was formed by suffixation. There were two suffix allomorphs— -[y] and -[u]—the distribution of which was determined by a group-specific alternation.

The set of items was created with a subset of the phoneme inventory of German. The artificial language needed to be as simple as possible, so we avoided using one phoneme in more than one position. We could not maintain this for the case of [m] in the AV item sets, because of our restriction on the number of phonemes in the inventory and for a phonotactic reason: We only allowed forms that did not violate the requirements of German phonotactics (for example, we did not use [ŋ] after tense vowels [Féry, 2001; Wiese, 1996]). This resulted in some lexical gaps, but they are evenly distributed across the item set. For the VH item sets of singular forms we used [m, n, j, l, f, d, k, z] in onset position and [t, s, ʃ, p, ŋ] in coda position. For all consonant positions we prepared these subsets of the German phoneme inventory such that the phoneme inventory of the artificial language varies in terms of place and manner of articulation, continuancy, and voice. The same subset was used for the AV item sets of singular forms except that we needed to use [m] instead of [ŋ] in coda position as a consequence of the phonotactic restrictions of German. For VH items, the intermediate stem vowel was taken from a set of three [+back] [o, ɔ, ʊ] and three [–back] [ɪ, e, œ] vowels. For AV items, the intermediate stem vowel was taken from a set of three [tense] and three [lax] vowels, [o, a, e] and [ɪ, ʊ, œ]. There is an overlap of 5 out of 6 stem vowels for both types of alternations; the VH and AV sets of items were as similar as possible. Within each set we counterbalanced the characteristics of all the features not involved in the set affiliation; for instance, tense and lax vowels varied across the dimensions of backness and height.

The procedure resulted in a core lexicon of 240 singular forms (8 onset consonants × 6 stem vowels × 5 coda consonants) for each alternation type. Because of the phonotactic restrictions the VH set was reduced to 224 possible singular forms. There were no phonotactic restrictions on the AV training set, but we adjusted this set so that for both alternation types we could use the same number of items: in analogy to the excluded VH tokens with a tense stem vowel and the coda consonant [ŋ], we excluded the same number of AV tokens with a tense stem vowel and the coda consonant [m].

Based on the type of coda consonant, which was not involved as a trigger or target in any type of alternation, we divided the item sets of singular forms into a training set and a test set. The 128 items with the coda consonants [t, ʃ, ŋ/m] were used for training and 96 items with the coda consonants [s, p] were used in the test phase.

In the VH groups, the backness of the stem vowel determined the backness of the suffix: A front stem vowel triggered a front allomorph and a back stem vowel triggered a back allomorph. Thus, a singular form like [kɪt] corresponds to the plural [kɪty] and a singular form like [kʊt] corresponds to the plural [kʊtu]. In the AV groups the tenseness of the stem vowel determined the backness of the suffix: A tense stem vowel triggered a front allomorph and a lax stem vowel triggered a back allomorph. Thus, a singular form like [kot] corresponds to the plural [koty] and a singular form like [kʊt] corresponds to the plural [kʊtu]. For half of the participants of each AV group we created a counterrule (AV2): A tense stem vowel triggered a back allomorph and a lax stem vowel triggered a front allomorph. Since the relation between tenseness and backness is phonetically arbitrary, we wanted to ensure that the data were based not only on one specific assignment but on both possible ones. For the analyses we collapsed both groups. We decided not to include such a counterrule for the VH group. As described above, vowel harmony is a substantively based pattern since it is phonetically motivated. We decided to stick to that rule and not include the possible counterrule of a vowel disharmony, since this kind of rule is also phonetically motivated, although the mechanisms behind the motivation are different. A disharmony is a kind of long-distance dissimilation and results in a better perceptual differentiation of the trigger and target (Zsiga, 2013). Dissimilation patterns as well as assimilation patterns are known to be cognitively biased (Wilson, 2003). However, in the present study we want to concentrate on the influence of the harmony's phonetic motivation and thus we remained with the harmony as a majority pattern. In both types of alternations, trigger (stem vowel) and target (suffix allomorph) were adjacent on the vowel tier. In the tradition of non-linear phonology (Goldsmith, 1976) the dependencies under investigation—although not string-adjacent—are local on a different tier (Finley, 2009; Kaun, 2004).

The second factor under investigation in our experiment was the regularity of the morphophonemic alternation. We trained participants with some plural forms that were exceptions; these exceptional items in our paradigm followed the opposite pattern to the intended major pattern. We investigated two degrees of regularity: 65% and 85%. In the 85 conditions 85% of the plural forms followed one rule and 15% the opposite one; in the 65 condition 65% followed one rule and 35% the opposite one. The general formation of plural forms in the majority and minority—exceptional—alternation types is summarized in Table 3. Complete lists of the training and test items are provided in the Appendix Tables A1–A4.[1]

So far we have explained the training of the participants. The following section describes the final makeup of the complete training item sets. All training item sets consisted of 50% singular forms and 50% plural forms. The total number of items in the training was n = 128. Of the 64 plural forms in one item set, either 85% or 65% followed a majority VH or AV alternation. This means that a total of 54 or 42 items followed the majority alternation. The minority—15% or 35%—of plural forms in one item set then followed the exceptional pattern. This means that a total of 10 or 22 items followed the minority alternation. We determined by random choice which items belonged to the minority and which items really followed the majority rule. The exceptions for the 85% conditions were a subset of the exceptions of the 65% conditions. All training items were

Table 3
Alternation types

	$0 \rightarrow V_{2[-\text{back}]}$	$0 \rightarrow V_{2[+\text{back}]}$
VH: Vowel harmony		
VH	$0 \rightarrow V_{2[-\text{back}]}/CV1_{[-\text{back}]}C\_\#$	$0 \rightarrow V_{2[+\text{back}]}/CV1_{[+\text{back}]}C\_\#$
VH exceptions	$0 \rightarrow V_{2[-\text{back}]}/CV1_{[+\text{back}]}C\_\#$	$0 \rightarrow V_{2[+\text{back}]}/CV1_{[-\text{back}]}C\_\#$
AV1: Arbitrary vowel alternation		
AV1	$0 \rightarrow V_{2[-\text{back}]}/CV1_{[\text{tense}]}C\_\#$	$0 \rightarrow V_{2[+\text{back}]}/CV1_{[\text{lax}]}C\_\#$
AV1 exceptions	$0 \rightarrow V_{2[-\text{back}]}/CV1_{[\text{lax}]}C\_\#$	$0 \rightarrow V_{2[+\text{back}]}/CV1_{[\text{tense}]}C\_\#$
AV2: Arbitrary vowel alternation		
AV2	$0 \rightarrow V_{2[-\text{back}]}/CV1_{[\text{lax}]}C\_\#$	$0 \rightarrow V_{2[+\text{back}]}/CV1_{[\text{tense}]}C\_\#$
AV2 exceptions	$0 \rightarrow V_{2[-\text{back}]}/CV1_{[\text{tense}]}C\_\#$	$0 \rightarrow V_{2[+\text{back}]}/CV1_{[\text{lax}]}C\_\#$

presented in random order. For each alternation type we created two versions of the training item set to avoid item-specific or sequence-specific effects. This resulted in 12 training item sets—two VH training item sets and four AV training item sets (2 × AV1, 2 × AV2) per regularity condition. For the test phases the whole test item set for the VH or AV alternation of 96 items was randomized.

2.1.1.2. Recording of materials: The stimuli were recorded by a phonetically trained, female native speaker of German. She knew that the stimuli would be used for an ALP experiment, but she was not aware of the purpose of the experiment. All stimuli were recorded in an anechoic chamber. They were embedded in the carrier sentence *Ich habe X gesagt.* ("I said X."). The bisyllabic plural forms were produced with stress on the first syllable. We extracted the target stimuli and scaled their intensity to 70 dB using Praat software (Boersma & Weenink, 2009).

2.1.1.3. Participants: We asked 80 healthy adult German native speakers to participate in our experiment. They were students at the University of Potsdam and were given course credit or a small amount of money for their participation. No participant studied linguistics. All of them had normal hearing and normal or corrected vision, and none of them reported any neurological problems. The participants had a mean age of 22;6. Sixty-seven of them were women and 13 were men; 5 of them were left-handed and 75 were right-handed. The highest educational degree of nearly all of them was the German secondary school diploma; two of our participants held a university degree in a non-linguistic subject of study. With a language history questionnaire we ensured that no participant knew a language with vowel harmony. Participants were randomly assigned to the four experimental groups VH-85, AV-85, VH-65, and AV-65 and the associated training and test sets.

2.1.1.4. Procedure: Before the training the participants were instructed that they were going to listen to an artificial language which is not similar to German or any other language. To become familiar with the setup of the experiment, we presented participants with a short introduction with six German examples of auditory and visual stimuli. The participants' task during training was to look and listen; the instructions did not contain hints regarding training or learning or any metalinguistic advice. During the training phase, participants listened to singular and plural forms accompanied by the visual support of the corresponding picture of the object(s). The input did not contain singular ~ plural pairs but randomly chosen singular or plural forms from the group-specific item set. There was one repetition of the training phase; this second round was identical to the first one in type, number, and order of training items.

For the test phase, participants were asked to form plurals of given new singular forms (Berko-Gleason, 1958) using the patterns of the artificial language they had listened to before: We gave a singular form plus the accompanying picture of an object followed by a picture of two of these objects, thus prompting the participants to form the plural. The participants' answers were recorded for the purpose of analysis. The experiment took place in a quiet room at the University of Potsdam. Headphones, a microphone, and a computer were used. The experiment took approximately 15 min.

2.1.2. Results of the experiment series 1

The recorded responses were transcribed twice in random order by the first author. We documented whether the participants' answers were realized with -[y], thus a front suffix, or -[u], a back suffix. The reliability of the two rounds of transcriptions was 100% for the 7,648 answers that could be used in the analysis. The remaining 32 answers (7680 possible answers [80 participants × 96 items]) were not included in the analysis due to background noise or other technical problems. The two suffixes were equally distributed across the overall set of answers; there were 3,817 -[y] answers and 3,831 -[u] answers (Fisher's Exact test, two-tailed $p = 0.90$).

2.1.2.1. Analysis of the overall conformity with the majority alternation: We investigated whether and to what extent participants mirror their input in the new items. To do this, we counted whether the participants applied the majority alternation of the training phase to the new items of the test phase. The highest mean was reached in group AV-85 with 61.1% conformity to the majority alternation, followed by VH-85 with 54.8%, VH-65 with 53.4%, and AV-65 with 51.0%.

We first present the results of a generalized linear mixed-effects model with conformity as the dependent variable. All data were analyzed using R (R Development Core Team, 2011) and the R packages lme4 (Bates, Maechler, & Bolker, 2011) and languageR (Baayen, 2008) for the generalized linear mixed-effects model with treatment coding. We included the type of alternation and the degree of regularity as fixed effects, both categorical and discontinuous: VH versus AV in type of alternation and 85% versus 65% in degree of regularity. As random factors, we included both participant and item, where each participant and item was given a random slope for each fixed factor. Only the degree of regularity emerged as a significant predictor, while type of alternation and the interaction between both factors did not; see Table 4. With a regularity of 85% the odds of a majority-conform answer are 1.75 times higher than with a regularity of 65% (odds ratio as the exponentiated coefficients in the column *Estimate* of Table 4).

We believe that this analysis is dissatisfactory. The analysis of conformity requires a two-dimensional view in that participants either succeeded and applied the alternation above chance level, showing that they were sensitive to an input majority alternation, or failed and performed at chance level, as expected from a binary decision between two suffixes in $n = 96$ test items. However, our data show a greater variability (see Fig. 1). We found three kinds of responders: correct (*positive* learners), correct-but-inverted—a minority rule is taken to be the majority rule and vice versa (*negative* learners)—and chance (*guessers*) responders.[2] Although negative learners clearly did not learn the whole alternation, they showed particular sensitivity to the features involved in the alternation. We believe that the relatively high number of negative learners in all groups can be understood as a consequence of the unreliable learning situation the participants found themselves in. Results of the negative learner could now cancel out the results of the

Table 4
Experiment series 1: Results of the generalized linear mixed-effects model with overall conformity to majority alternation as a dependent variable

	Estimate	*SE*	*z* value	*Pr*(>|*z*|)
(Intercept: Grand mean)	0.6004	0.2665	2.253	0.0243
Type of alternation (Baseline: AV)	−0.3527	0.3253	−1.084	0.2783
Degree of regularity (Baseline: 85%)	−0.5580	0.2789	−2.000	0.0455
Type of alternation × Degree of regularity	0.4687	0.3573	1.312	0.1895

positive learners. For illustration of this effect we simulated the performance of a hypothetical group which we call guessers. Their individual scores would look like the ones in Fig. 2. Since the analysis of conformity does not capture the negative learners' performances, we now present a second analysis in which the distance from chance level is the dependent variable instead.

2.1.2.2. Analysis of the distance from chance level: We found three kinds of responders and we argue that the performance of a negative learner should be judged better than that of a guessing participant. The variability in the data is especially interesting in the light of Baer-Henney and van de Vijver's (2012) study, in which the same types of alternation were learned during an artificial language learning experiment without exceptions. The circumstances of the learning environment were much more reliable, and we attribute the variability in the data of the present experiment to the unreliable and variable environment of an artificial language that includes alternations with exceptions.

To capture the degree of success in negative learners, we need to understand that acquisition of a phonological pattern just like the one under investigation involves an intermediate second step: the realization that there is a dependency between the two vowels based on certain features. Research agrees that learning is a stepwise procedure (Levelt & van de Vijver, 2004) and so we assume that we are observing such a development here. After the first step in learning—the identification of two allomorphs—which all of our participants successfully discovered, there is a second step, which is the discovery that the choice of the allomorph is dependent on some characteristic of the stem vowel (here: backness or tenseness determines the backness of the suffix). The features involved need to be identified. Positive as well as negative learners—but not guessers—have successfully completed this step. Finally, there is a third step, namely recognizing the specific property of the stem vowel that determines the choice of the suffix allomorph (here: that a lax stem vowel triggers the front suffix or a front stem vowel triggers the front suffix), which has only been reached by positive learners. This point of view allows us to look at the data from a different perspective: We now ask ourselves, how many participants completed the intermediate step of acquisition? Hence, in the following section we analyze the participants' absolute distances from the chance level rather than their overall conformity to the majority alternation. In a two-dimensional decision between plural allomorphs, we assume that the chance level is at 50%. Thus, to get the distance from the

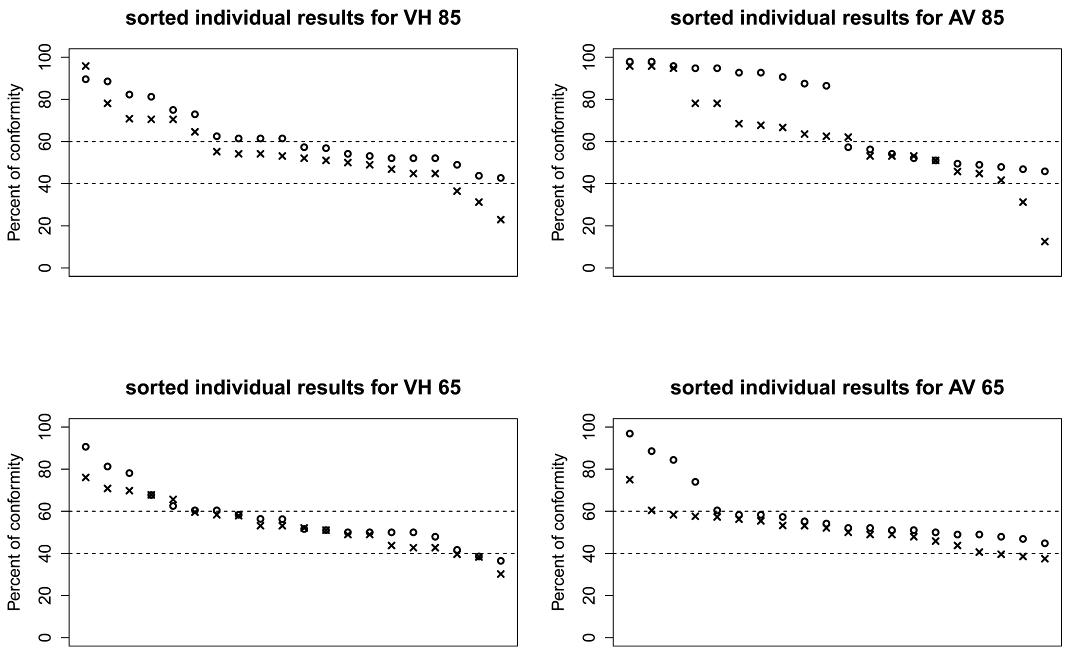

Fig. 1. Individual conformity scores for the majority alternation in all groups (VH-85, AV-85, VH-65, AV-65) of experiment series 1 (crosses) and 2 (circles). The area between the dashed lines marks the expected chance level given a binary decision for all items.

chance level we counted how much the participant differed from the chance level. A participant that reached 80% conformity then scored 30% and so did a participant that scored 20%.

The highest mean distance from chance level was reached by group AV-85 with 18.4%, followed by VH-85 with 12.2%; VH-65 reached 10.0% and AV-65 reached 6.9%. Our simulation of a group of guessers makes it possible to provide a hypothetical mean distance of 3.7% in this group. As above with the conformity data, we look at the individual data first; see Fig. 3. As a comparison, we additionally present how the data of the hypothetical group of guessers would look in Fig. 4.

We calculated a generalized linear mixed-effects model (Baayen, 2008; Bates et al., 2011). As fixed effects we included the type of alternation and the degree of regularity, again both categorical and discontinuous: VH versus AV in type of alternation and 85% versus 65% in degree of regularity. Since the current analysis is on aggregated data, item is no longer available as a random factor. A model with participant as random factor turned out to be the most reliable one. Type of alternation emerged as a marginally significant predictor. In AV learners the odds of a higher distance from chance level are 2.3 times higher than in VH learners. Again, degree of regularity emerged as a significant predictor: with a regularity of 85% the odds of reaching a high distance from chance level are 4.3 times higher than with a regularity of 65%. Moreover, the interaction between the fixed factors reached significance. The results of the main comparison are summarized in Table 5.

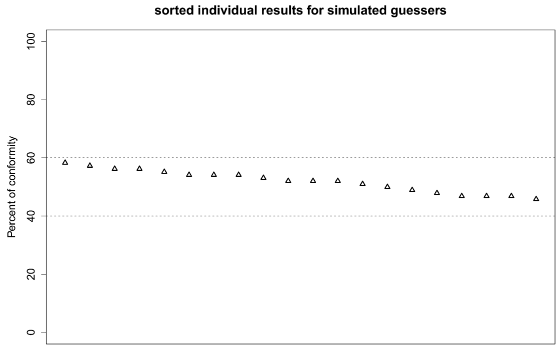

Fig. 2. Individual conformity scores for the majority alternation in a simulated hypothetical group of participants performing at chance level. The area between the dashed lines marks the expected chance level given a binary decision for all items.

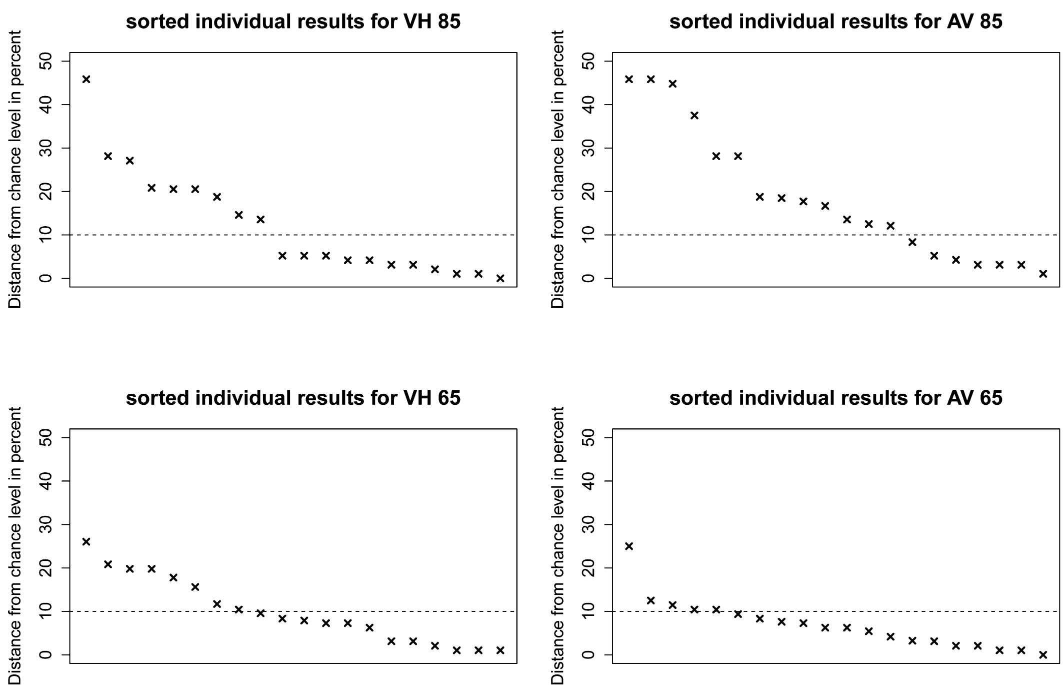

Fig. 3. Individual distances from chance level in all groups (VH-85, AV-85, VH-65, AV-65) of experiment series 1. The area below the dashed lines marks the expected chance level given a binary decision for all items.

A look at the interaction graph in Fig. 5 confirms what the mean distances from chance level in all groups have demonstrated: learners generalized the input pattern of the AV-85 condition to novel items more often than Learners in the VH-85 condition. When the input contains more exceptions, the learners' generalizations are reversed: In the VH-65 condition learners generalized the alternations to new items more often than in the AV-65 condition.

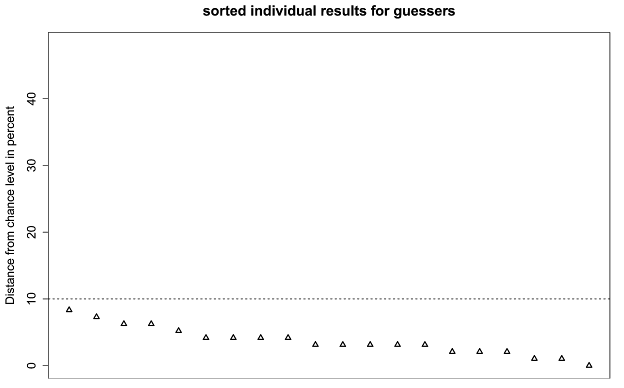

Fig. 4. Individual distances from chance level in the hypothetical group of guessers. The area below the dashed lines marks the expected chance level given a binary decision for all items.

Table 5
Experiment series 1: Results of the generalized linear mixed-effects model with distance from chance level as a dependent variable

	Estimate	*SE*	*z* value	*Pr*(>|*z*|)
(Intercept: Grand mean)	−0.7380	0.3156	−2.339	0.01935
Type of alternation (Baseline: AV)	−0.8410	0.4500	−1.869	0.06164
Degree of regularity (Baseline: 85%)	−1.4493	0.4521	−3.206	0.00135
Type of alternation × Degree of regularity	1.3039	0.6396	2.039	0.04149

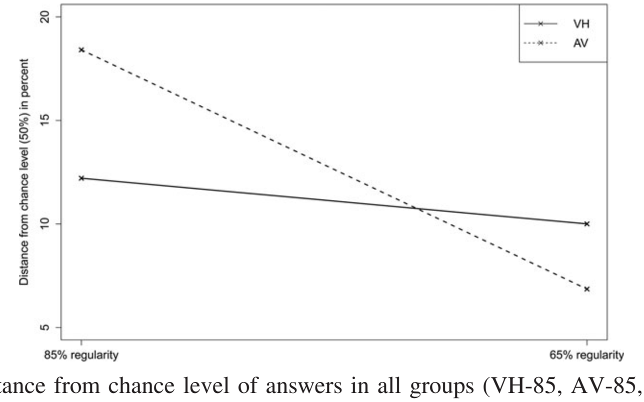

Fig. 5. Mean distance from chance level of answers in all groups (VH-85, AV-85, VH-65, AV-65).

2.1.2.3. Post-hoc analyses: For post-hoc analyses we used the exact binominal test (Hollander & Wolfe, 1973). To do so, we chose the two subgroups of interest and simulated 1,000,000 samples from a population that has the same properties as one experimental subgroup. The results (in distance from chance level) of this simulated sampling can be graphed as a density curve and we are able to show the area within which 95% of the

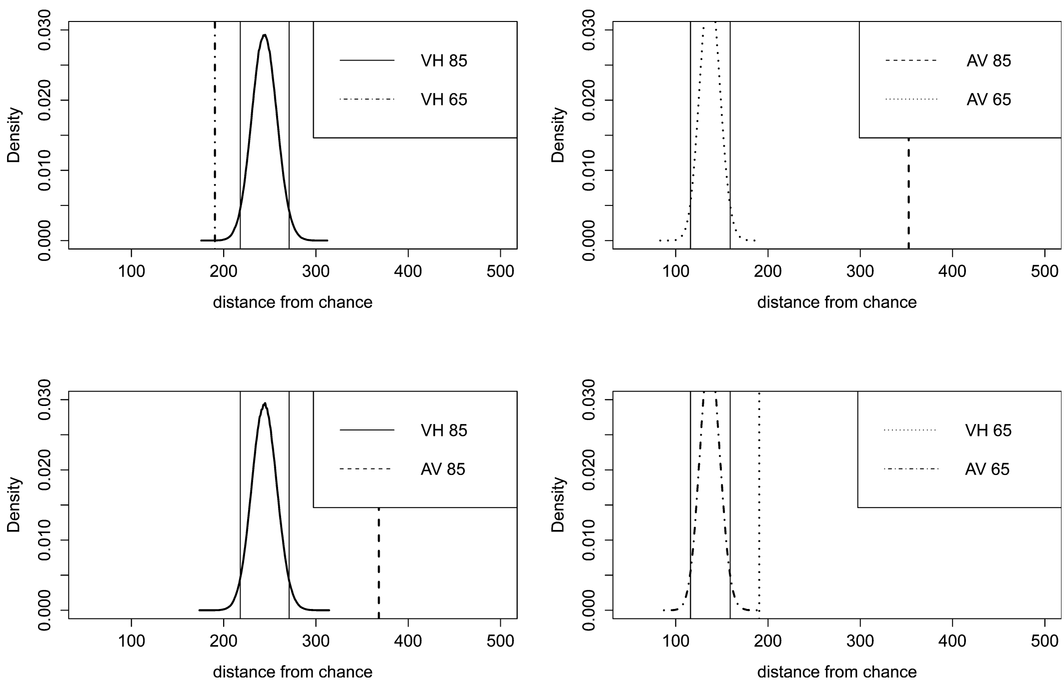

Fig. 6. Post-hoc analyses: subgroup comparisons. Solid lines at the edge of the curve mark the 95% confidence intervals of the samplings.

simulated samples fall. Subsequently we tested whether the mean distance of the counter-subgroup falls within the 95% confidence interval of the sampling. If yes, then the subgroups would not differ. However, the comparisons show the opposite: Group AV-85 has a significantly higher distance than group VH-85, and group AV-65 is also different from group VH-65. In the 65 groups, however, the direction is reversed. VH has a significantly higher distance than AV. Within each type of alternation, the group with 85% regularity has a significantly higher distance than the group with 65% regularity. Results of multiple group comparisons are shown in Fig. 6.

In Fig. 7 we show likewise that—apart from what could be assumed from the mean conformity performances of the subgroups—there is indeed more in the data: Neither experimental group behaves like the hypothetical group of guessers; that is, participants that would all have performed at chance level.

2.2. *Experiment series 2*

If it is true that negative learners just lack the third step of learning the correct alternation, then the analysis of conformity in experiment series 1 does not provide an accurate analysis of the data. On the contrary, it could be the case that negative learners internalized and thus regularized the minority pattern. There are studies in which learners tend to regularize irregular patterns. In these cases learners reorganize their input and cre-

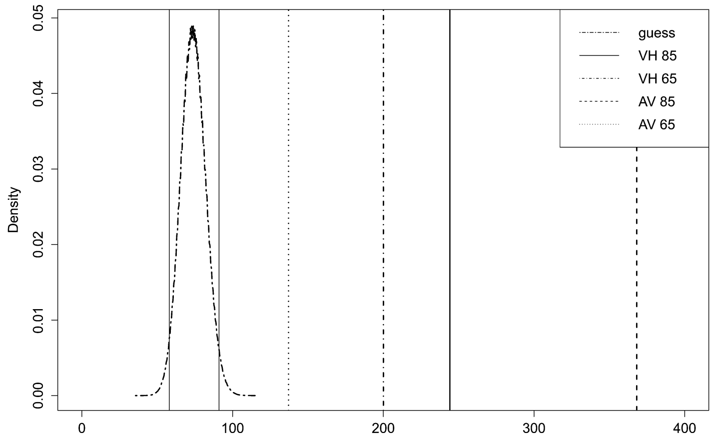

Fig. 7. Post-hoc analyses: subgroup comparisons versus guessers. Solid lines at the edge of the curve mark the 95% confidence interval of the sampling.

ate their own patterns in their linguistic system. The inconsistent input is not simply mirrored, but some patterns among others are regularized by adult learners when applied to new forms (Wonnacott & Newport, 2005). However, while adult learners sometimes imitate the probabilistic distribution of just learned inconsistent patterns and regularize only under certain circumstances, children tend to regularize more readily (Hudson Kam & Newport, 2009). We need to find out then whether negative learners have regularized the irregular minority pattern or whether they are on the right track toward acquiring the majority pattern in that they have learned the second step but not yet discovered the third. A new series of experiments with a longer training phase was conducted to help to distinguish between the two possibilities. Thus, if negative learners regularized the minority pattern, we would expect them to stick with this performance even after longer exposure. However, if they were caught in the intermediate step of learning due to the shorter training time, we would expect them to conform more to the majority pattern instead after longer training. If we could find evidence for the second possibility, this would justify our analysis of the distance from chance level as well. We ran a second series of experiments with longer training times and new participants. The experimental setup apart from the lengthened training phases remained the same.

2.2.1. Method, design, and hypotheses

The method, design, and hypotheses were the same as in the first series of experiments. We now investigated the performances of participants after encountering a longer training phase.

2.2.1.1. Design of stimuli and recording of materials: The same set of stimuli as in the experiment series 1 was used.

2.2.1.2. Participants: We asked 80 healthy adult German native speakers who had not participated in the first experiment to participate in our experiment. They were students at the University of Düsseldorf and were given course credit for their participation. Again, all of them had normal hearing and normal or corrected vision, and none of them reported any neurological problems. The participants had a mean age of 21;5. Sixty-five of them were women and 15 were men; 7 of them were left-handed, 72 were right-handed, and 1 was ambidextrous. Nearly all of them had a German secondary school diploma as their highest educational degree so far, which qualified them for university entrance; two of our participants held a lower school degree. We also ensured that no participant knew a language with vowel harmony. Participants again were randomly assigned to the four experimental groups VH-85, AV-85, VH-65, and AV-65 and the associated training and test sets.

2.2.1.3. Procedure: The procedure of experiment series 2 was the same as in the first series with the only difference being a longer training phase. Instead of the previous two repetitions of the training phase, participants now were exposed to three repetitions of it. All rounds were identical in type, number, and order of training items. The experiment took place in a quiet room at the University of Düsseldorf. It took approximately 20 min.

2.2.2. Results of the experiment series 2

The first author transcribed the responses of the second experiment series twice in random order and again the reliability of the two transcriptions was 100%. A total of 7,675 answers went into the analysis, while 5 answers needed to be excluded because of noise. The two suffixes were not equally distributed across the overall set of answers; there were 3,717 -[y] answers and 3,958 -[u] answers (Fisher's Exact test, two-tailed $p = 0.03$).

2.2.2.1. Analysis of the overall conformity with the majority alternation: Concerning the second experiment series, we will only present and analyze the conformity data since an analysis of the distance of chance level would reveal nothing new. As expected, the performances in the experiment series with longer training times were better in all groups ($\beta = -0.4$; $SE = 0.14$; $p = 0.004$). The highest mean conformity was again reached in group AV-85 with 72.1% conformity to the majority alternation, followed by VH-85 with 62.5%. Contrary to in the first experiment series, AV-65 was more successful with 59.1% than VH-65 with 57.0%.

In fact, there were very few negative learners left. For a comparison of the individual performances in both experiment series, see Fig. 1. We again ran a generalized linear mixed model in which we included both participant and item as random factors, where each participant and item was given a random slope for each fixed factor. In line with the analysis of the distance of the chance level the model shows that type of alternation and degree of regularity are significant predictors; see Table 6. With a regularity of 85% the odds of a majority-conform answer are 2.56 times higher than with a regularity of 65%. The odds of a majority-conform answer are 2.24 times higher in the AV condition than in the VH condition. However, the interaction was not significant.

2.2.2.2. Post-hoc analyses: Post-hoc analyses and subgroup comparisons of the data with longer training phases were performed identical to those of the first experiment series in

Table 6
Experiment series 2: Results of the generalized linear mixed-effects model with overall conformity to majority alternation as a dependent variable

	Estimate	*SE*	*z* value	*Pr*(>|*z*|)
(Intercept: Grand mean)	1.3824	0.3263	4.236	2.28e−05
Type of alternation (Baseline: AV)	−0.8059	0.3613	−2.230	0.0257
Degree of regularity (Baseline: 85%)	−0.9383	0.3704	−2.533	0.0113
Type of alternation × Degree of regularity	0.6821	0.4267	1.599	0.1099

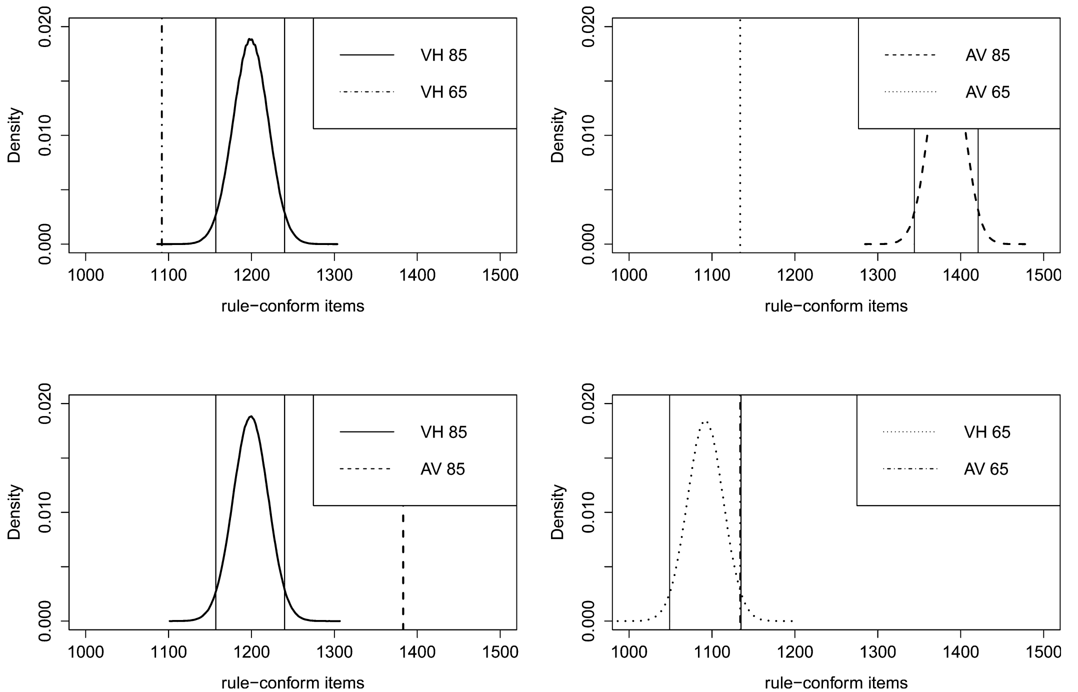

Fig. 8. Post-hoc analyses: subgroup comparisons of the experiment series 2. Solid lines at the edge of the curve mark the 95% confidence interval of the sampling.

section 2.1.2. These revealed that within each type of alternation the 85% group performed better than the 65% group. And again, when presented with fewer exceptions, the AV group performed better than the VH group. In contrast to experiment series 1, in which participants trained with AV and VH with more exceptions differed, we observe a null result. Both groups perform at the same level; see Fig. 8.

3. Discussion

In our experiments we exposed different groups of adult native German speakers to an artificial language that contained morphophonemic alternations with exceptions. The artificial input displayed certain tendencies in the artificial lexicon: One pattern determined the majority of the input, while there was also a minority pattern that determined the shape of exceptional forms. Experimental groups differed with respect to type of alternation, regularity, and length of training. There were two types of alternations, namely a vowel backness harmony and an arbitrary vowel alternation. The first one benefits from its basis in substance, while the latter one benefits from certain aspects of phonotactics of the native language of the participants. Across groups we varied the degree of regularity: for each type of alternation we had one group with more exceptions (35%) and one group with fewer exceptions (15%). We ran the experiment with a shorter and a lengthened training phase. All factors differed between participants.

As expected, a pattern with fewer exceptions was adopted more readily than a pattern with more exceptions whether trained for a longer or for a shorter period of time. For the type of alternation, the success of feature identification and hence of making progress in the course of acquisition depended on the structural stability as well as on the length of training: With shorter training times, participants found it easier to detect a pattern in the arbitrary vowel alternation than in the vowel harmony, provided the pattern had few exceptions. With more exceptions, the features of the vowel harmony were identified faster than those of the arbitrary vowel alternation. That means that with only little training and depending on the amount of regularity, different cues contributed to the acquisition to different degrees: In a more reliable situation the learner benefited most from phonotactic support, but also benefited from substance, as all of the experimental groups differed significantly from a hypothesized group of guessers. Experimental groups in a less reliable situation, that is, with more exceptions, also benefited from phonotactic support and substance. In that situation, however, substance turned out to be the most reliable factor; the phonotactic support was still beneficial but was not as important as the amount of support from substance.

In order to justify our analysis of the first experiment series with a shorter training phase in which we find a high amount of variability, we ran a second experiment series with an extended training phase. As expected, the variability diminished with a longer training phase. And again, when faced with fewer exceptions, the acquisition of the arbitrary vowel alternation was learned more easily than the vowel harmony. Contrary to the findings of the first experiment series, there was no learning difference between vowel harmony and the arbitrary vowel alternation now that the training lasted longer. A lengthened training phase can also function as a stabilizer during the training. As a consequence, not only the variability in the data diminished but also the learning situation of those participants that needed to learn either vowel harmony or the arbitrary vowel alternation with many exceptions became easier. Hence, learners of the arbitrary vowel alternation caught up and performed as well as vowel harmony learners. In general we found that our adult learners use all factors that we investigated during the course of development. But we also found that the acquisition of morphophonemic alternations is a complex and highly variable matter; acquiring an unreliable distribution—alternations with exceptions—is even harder. Learners use all resources available. Our data show that learning is more than a steady progression towards a target competence—it can be influenced by phonotactics as well as substance and the length of exposure.

These findings contradict usage-based theories that predict the frequency of occurrence to be the sole influential factor (Bybee, 2001; Tomasello, 2003), but tie in with and augment other recent findings that the course of development is influenced by many supporting factors in addition to frequency. Recent studies discuss the role of universal factors like substance (Finley, 2012b; Redford, 2008; van de Vijver & Baer-Henney, 2012b; Wilson, 2006) and more specifically, the role of knowledge of natural classes (Baer-Henney & van de Vijver, 2012; Cristià et al., 2011; Skoruppa & Peperkamp, 2011) as well as the frequency of a pattern and of locality (Baer-Henney & van de Vijver, 2012; Finley, 2012a; Newport & Aslin, 2004).

We have shown that adult participants strongly rely on what their language-specific grammar is equipped with: the native language's phonotactics. We have demonstrated that the distinction of tense and lax vowels is of extraordinary importance during acquisition for German adult learners, more so than the front/back distinction (Kleber et al., 2010; Ott, 2011). This knowledge helps them to group stems on the basis of their vowels and to identify the features involved in the non-native alternation pattern quickly. Moreover, the fact that native speakers use the phonotactics of their language shows that they consider the task—learning an artificial language—a language-learning task, and not just a task of learning general cognitive patterns.

We have also shown that German native speakers who are not familiar with harmony patterns are able to make progress in learning a vowel backness harmony. The universal factor of phonetic grounding of this type of alternation (Kaun, 1995; Ohala, 1994) helps the learners to get on the right track in recognizing the usage of front versus back allomorphs based on the backness status of a stem vowel. With our findings we join a growing body of literature that argues for a substantive bias in the acquisition of alternations in adults (Baer-Henney & van de Vijver, 2012; Cristià & Seidl, 2008; Finley, 2012b; Wilson, 2006) and children (van de Vijver & Baer-Henney, 2012b) and extend the impact of the bias to the scenario of the acquisition of alternations with exceptions, which had not been investigated up till now.

We believe that learners can cope with the task of acquisition better if they are equipped with cognitive biases than if they are not. Biases in general constrain the learning task and provide additional support for purely statistical learning algorithms. Our findings tie in with and augment other recent findings stating that the course of development is supported by many factors in addition to frequency, and contradict usage-based theories. The question remains as to where such biases come from. While the influence of a language-specific factor like phonotactics is clearly dependent on the ambient language, it remains unclear where a universal bias for substantively based patterns could come from. In a nativist view it could be conceivable that these kinds of biases are innate as part of the Universal Grammar (Becker et al., 2011; Chomsky & Halle, 1968). There is, however, an alternative account that supposes that substantive biases emerge through phonetic experience (Hayes, Kirchner, & Steriade, 2004). Support for this account comes from Cristià and Seidl (2008) and Cristià et al. (2011). In these studies, infants were tested with the headturn preference paradigm on whether they are able to extend a pattern that groups only non-continuant sounds together to other untrained non-continuants, as well as extend a pattern that groups continuants and non-continuants together to untrained non-continuant sounds. While 7-month-olds succeeded in the first condition but failed in the second (Cristià & Seidl, 2008), 4-month-olds suceeded in both patterns and did not show a difference (Cristià et al., 2011). It seems that the perceptual bias emerged between the critical period of 4 and 7 months. Had the bias been innate, 4-month-olds would have been expected to also show the asymmetry. It is thus reasonable to conclude that the bias for substantively based patterns emerges from the learners' experience with their own perceptual or articulatory systems. A principle that eases everyday life is readily adopted. If it is the case that the substantive bias emerges from experience, then a bias for vowel harmony patterns such as we have shown should not be exhibited by newborns, but should arise with time.

Psychologists and linguists have just begun to investigate this question. We believe that there are many open questions and that the search for answers can benefit from the powers of ALP experiments and laboratory phonology. We are aware that there are many ways in which the present experiments could be complemented by follow-up studies. For instance, if the universal bias of substance arises through the actual use of the perceptual and/or articulatory systems, then it should be possible to show that it is a gradient rather than a categorical factor. A pattern cannot be either based entirely in substance or not at all; it can be based in substance to a lesser or greater degree. And if the substantive bias is gradient rather than categorical, we would expect a learning advantage for harmonies that involve triggers and targets that are perceptually or productively more similar compared to harmonies that involve triggers and targets that are perceptually or productively less similar. For further support of the influence of language-specific factors like L1 phonotactics, speakers of another language in which there is no special role of tenseness are expected to perform less well on learning our arbitrary alternation. Further, a disharmony condition could be tested in which the minority pattern is the harmony and the majority pattern is the disharmony. Wilson (2003) compared the acquisition of a nasal harmony and disharmony compared to a random pattern and found an equally strong bias for both alternations. Moreover, one could test a condition with a substantively based alternation which also plays a role in L1 phonotactics such as a tenseness harmony in German learners or a pattern that is neither substantively based nor crucial for the L1 phonotactics.

The present study has shown, however, that depending on the amount of irregularity and training, the language-specific knowledge and the universal factor of substance act as supportive factors during the acquisition of alternations. That is, the acquisition of a less systematic and less trained alternation is supported most by substance, while the acquisition of a more systematic pattern is boosted by the learner's language-specific knowledge.

4. Conclusion

We investigated the acquisition of artificial morphophonemic alternations with exceptions. We found that participants have difficulties and that there is a great amount of variability among them. With an additional experiment in which we lengthened the exposure to a pattern, the variability could be reduced. Nevertheless, we showed that learners are on the right track, and along the way they can benefit from different sources of information. The universal factor substance can act as a bias in that a phonetically grounded pattern may be adopted more readily than a pattern which is not. Furthermore, the learner can benefit from knowledge from L1 phonotactics, which is a language-specific factor. Phonological knowledge of the native language can strongly help learners adopt a pattern which relies on this knowledge as compared to another pattern which does not. Which cue turns out to be the most reliable one is a matter of degree of regularity and length of training. Only in the least stable situation—with less training and a low degree of regularity—does substance act as the stronger bias. The more training and the more regular the patterns become, the stronger the influence of L1. Our data contribute to the current debate on how alternations are learned. We show that the course of development is far from straightforward; many factors affect the course of acquisition. Our experiments show that universal and language-specific factors interact during the acquisition of morphophonemic alternations with exceptions.

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Notes

1. We are aware that our design results in a stylized phonological pattern: While the majority of items conforms to a vowel harmony, the minority of items—our exceptions—conforms to a vowel disharmony which is the logical counterpart of the harmony. In natural languages such exceptional patterns are unlikely. Various factors determine the shape of exceptions, such as default markers (Hayes et al., 2009). The actual shape of exceptions is a complex issue and not within the scope of the present experiment. We decided in favor of the logical counterparts to keep design of the artificial language simple.
2. The three-level distinction of learner groups is our own decision. We further describe the criteria by which we grouped learners. To our knowledge there is no literature on how to deal with the asymmetrical learning behavior.

References

Albright, A., & Hayes, B. (2003). Rules vs. analogy in English past tenses: A computational/experimental study. *Cognition*, *90*(2), 119–161.

Baayen, H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge, England: Cambridge University Press.

Baer-Henney, D., & van de Vijver, R. (2012). On the role of substance, locality and amount of exposure in the acquisition of morphophonemic alternations. *Laboratory Phonology*, *3*(2), 221–249.

Bates, D., Maechler, M., & Bolker, B. (2011). Linear mixed-effects models using s4 classes. R package version 0.999375-42.

Becker, M., & Gouskova, M. (2013). Nonce words show that Russian yer alternations are governed by the grammar. *Natural Language & Linguistic Theory*, *31*(3), 735–765.

Becker, M., Ketrez, N., & Nevins, A. (2011). The surfeit of the stimulus: Analytic biases filter lexical statistics in Turkish laryngeal alternations. *Language*, *1*(87), 84–125.

Becker, M., Nevins, A., & Levine, J. (2012). Asymmetries in generalizing alternations to and from initial syllables. *Language*, *88*(2), 231–268.

Berko-Gleason, J. (1958). The child's learning of English morphology. *Word*, *14*, 150–177.

Boersma, P., & Weenink, D. (2009). Praat: Doing phonetics by computer [computer program]. Version 5.1.17. Available at http://www.praat.org/. Accessed October 5, 2009.

Bybee, J. (2001). *Phonology and language use*. Cambridge, England: Cambridge University Press.

Chomsky, N., & Halle, M. (1968). *The sound pattern of English*. New York: Harper and Row.

Clahsen, H. (1999). Lexical entries and rules of language: A multidisciplinary study of German inflection. *The Behavioral and Brain Sciences*, *22*, 991–1060.

Clements, G., & Sezer, E. (1982). Vowel and consonant disharmony in Turkish. *The Structure of Phonological Representations*, *2*, 213–255.

Coetzee, A. (2008). Grammaticality and ungrammaticality in phonology. *Language*, *84*(2), 218–257.

Coetzee, A., Lin, S., & Pretorius, R. (2007). Post-nasal devoicing in Tswana. In J. Trouvain & W. Barry (Eds.), *Proceedings of the International Congress of Phonetic Sciences XVI* (pp. 861–864), Dudweiler: Pirrot GmbH.

Cristià, A., & Peperkamp, S. (2012). Generalizing without encoding specifics: Infants infer phonotactic patterns on sound classes. In A. Biller, E. Chung, & A. Kimball (Eds.), *Proceedings of the 36th Boston University Conference on Language Development* (Vol. 1, pp. 126–138), Boston: Cascadilla Press.

Cristià, A., & Seidl, A. (2008). Is infants' learning of sound patterns constrained by phonological features? *Language Learning and Development*, *4*(3), 203–227.

Cristià, A., Seidl, A., & Gerken, L. (2011). Learning classes of sounds in infancy. *University of Pennsylvania Working Papers in Linguistics*, *17*(1).

Daland, R., Hayes, B., White, J., Garallek, M., Davis, A., & Norman, I. (2011). Explaining sonority projection effects. *Phonology*, *28*, 197–234.

R Development Core Team. (2011). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. ISBN 3-900051-07-0.

Ernestus, M., & Baayen, R. (2003). Predicting the unpredictable: Interpreting neutralized segments in Dutch. *Language*, *1*(79), 5–38.

Féry, C. (2001). *Phonologie des Deutschen. Eine optimalitätstheoretische Einführung*. Potsdam: Universitätsverlag.

Fikkert, P., & Freitas, M. (2006). Allophony and allomorphy cue phonological acquisition: Evidence from the European Portuguese vowel system. *Catalan Journal of Linguistics*, *5*, 83–108.

Finley, S. (2009). *Formal and cognitive restrictions on vowel harmony*. Ph.D. thesis, Johns Hopkins University.

Finley, S. (2012a), Testing the limits of long-distance learning: Learning beyond a three-segment window. *Cognitive Science*, *36*(4), 740–756.

Finley, S. (2012b). Typological asymmetries in round vowel harmony: Support from artificial grammar learning. *Language and Cognitive Processes*, *27*(10), 1550–1562.

Flege, J. (1982). English speakers learn to suppress stop devoicing. *Papers from the Eighteenth Regional Meeting of the Chicago Linguistic Society* (pp. 111–122). Chicago: Chicago Linguistic Society.

Goldsmith, J. (1976). *Autosegmental phonology*. Ph.D. thesis, MIT.

Gomes, C., & Manoel, C. (2010). Flexão de número na gramática de criança e na gramática do adulto. *Veredas*, *1*, 122–134.

Gouskova, M. (2012). Unexceptional segments. *Natural Language & Linguistic Theory*, *30*(1), 79–133.

Hall, T. (2000). *Phonologie: Eine Einführung*. Berlin, New York: Walter de Gruyter.

Hayes, B., Kirchner, R., & Steriade, D. (2004). *Phonetically based phonology*. New York: Cambridge University Press.

Hayes, B., & White, J. (2013). Phonological naturalness and phonotactic learning. *Linguistic Inquiry*, *44*(1), 45–75.

Hayes, B., Zuraw, K., Sipta′r, P., & Londe, Z. (2009). Natural and unnatural constraints in Hungarian vowel harmony. *Language*, *85*, 822–863.

Hollander, M., & Wolfe, D. (1973). *Nonparametric statistical methods*, 2nd edition. New York: John Wiley & Sons.

Hudson Kam, C., & Newport, E. (2009). Getting it right by getting it wrong: When learners change languages. *Cognitive Psychology*, *59*(1), 30–66.

Jusczyk, P. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.

Kager, R., & Shatzman, K. (2007). Phonological constraints in speech processing. In B. Los & M. van Koppen (Eds.), *Linguistics in the Netherlands 2007*, (pp. 100–111), Amsterdam: John Benjamins.

Kaun, A. (1995). *The typology of rounding harmony: An Optimality Theoretic approach*. Ph.D. thesis, University of California.

Kaun, A. (2004). The phonetic foundations of the rounding harmony typology. In B. Hayes, R. Kirchner, & D. Steriade (Eds.), *Phonetically based phonology* (pp. 87–116). New York: Cambridge University Press.

Kerkhoff, A. (2007). *Acquisition of morpho-phonology: The Dutch voicing alternation*. Ph.D. thesis, University of Utrecht.

Kleber, F., John, T., & Harrington, J. (2010). The implications for speech perception of incomplete neutralization of final devoicing in German. *Journal of Phonetics*, *38*, 185–196.

Klein, T. (2000). *"Umlaut" in optimality theory: A comparative analysis of German and Chamorro*. Tübingen: Niemeyer.

Köpcke, K. (1998). The acquisition of plural marking in English and German revisited: Schemata versus rules. *Journal of Child Language*, *25*(2), 293–319.

Kügler, F. (2012). Coda consonant cluster timing in English, German, and Swedish, manuscript. University of Potsdam.

LaCross, A. (2011), *The role of language-specific phonology: Tracking linguistic variables in Khalkha Mongolian*. Ph.D. thesis, University of Arizona.

Levelt, C., & van de Vijver, R. (2004). Syllable types in cross-linguistic and developmental grammars. In R. Kager, J. Pater, & W. Zonneveld (Eds.), *Constraints in phonological acquisition* (pp. 204–218). Cambridge, UK: Cambridge University Press.

Linebaugh, G. (2008). *Phonetic grounding and phonology: Vowel backness harmony and vowel height harmony*. Ph.D. thesis, University of Illinois.

Nevins, A. (2010). *Locality in vowel harmony*. Cambridge, MA: MIT Press.

Newport, E., & Aslin, R. (2004). Learning at a distance I: Statistical learning of non-adjacent dependencies. *Cognitive Psychology*, *48*(2), 127–162.

Ohala, J. J. (1994). Towards a universal, phonetically-based, theory of vowel harmony. *Proceedings of the 3rd International Conference on Spoken Language Processing* (pp. 491–494). Yokohama: Acoustical Society of Japan.

Ott, S. (2011). *Feld – fällt – fehlt: Untersuchungen zur Phonologie-Morphosyntax-Schnittstelle bei Kindern und Erwachsenen*. Ph.D. thesis, Potsdam: University of Potsdam.

Pater, J. (2004). Exceptions in optimality theory: Typology and learnability. Talk at the Conference on Redefining Elicitation: Novel Data in Phonological Theory. New York University.

Pater, J. (2007). The locus of exceptionality: Morpheme-specific phonology as constraint indexation. In L. Bateman, M. O'Keefe, E. Reilly, & A. Werle (Eds.), *University of Massachusetts Occasional Papers*. (Vol. 32, pp. 259–296). Amherst, MA: GLSA.

Phelps, E. (1978), Exceptions and vowel harmony in Hungarian. *Linguistic Inquiry*, *9* (1), 98–105.

Pierrehumbert, J. (2006), The statistical basis of an unnatural alternation. In L. Goldstein, D. Whalen, & C. Best (Eds.), *Laboratory phonology VIII, Varieties of phonological competence* (pp. 81–107). Berlin: Mouton de Gruyter.

Pycha, A., Nowak, P., Shin, E., & Shosted, R. (2003). Phonological rule-learning and its implications for a theory of vowel harmony. In G. Garding & M. Tsujimura (Eds.), *Proceedings of the 22nd West Coast Conference on Formal Linguistics*. Vol. *22* (pp. 423–435). Somerville, MA: Cascadilla Press.

Redford, M. (2008). Production constraints on learning novel onset phonotactics. *Cognition*, *107*(3), 785–816.

Ringen, C., & Heinämäki, O. (1999). Variation in Finnish vowel harmony: An OT account. *Natural Language & Linguistic Theory*, *17*(2), 303–337.

Rossion, B., & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwart's object set: The role of surface detail in basic-level object recognition. *Perception*, *33*(2), 217–236.

Rumelhart, D., & McClelland, J. (1986). On learning the past tenses of English verbs. In D. Rumelhart, J. McClelland, & P. R. Group (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition* (pp. 216–271). Cambridge, MA: MIT Press.

Schane, S., Tranel, B., & Lane, H. (1975). On the psychological reality of a natural rule of syllable structure. *Cognition*, *3*(4), 351–358.

Schulte-Körne, G., & Mathwig, F. (2001). *Das Marburger Rechtschreibtraining*. Bochum: Winkler.

Seidl, A., & Buckley, E. (2005). On the learning of arbitrary phonological rules. *Language Learning and Development*, *1*(3), 289–316.

Skoruppa, K., & Peperkamp, S. (2011). Adaptation to novel accents: Feature-based learning of context-sensitive phonological regularities. *Cognitive Science*, *35*(2), 348–366.

Snodgrass, J., & Vanderwart, M. (1980). A standardised set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*(2), 174–215.

Tomasello, M. (2003). *Constructing a language: A usage-based theory of language acquisition*. Cambridge, MA: Harvard University Press.

Vennemann, T. (1988). *Preference laws for syllable structure and the explanation of sound change: With special reference to German, Germanic, Italian, and Latin*. Berlin: Mouton de Gruyter.

van de Vijver, R., & Baer-Henney, D. (2011). Acquisition of voicing and vowel alternations in German. In N. Danis, K. Mesh, & H. Sung (Eds.), *Proceedings of the 35th Boston University Conference on Language Development*. Vol. *2* (pp. 603–615). Boston, MA: Cascadilla Press.

van de Vijver, R., & Baer-Henney, D. (2012a). Sonority intuitions are provided by the lexicon. In S. Parker (Ed.), *The sonority controversy* (pp. 195–218). Berlin: Walter de Gruyter.

van de Vijver, R., & Baer-Henney, D. (2012b). Voice more, front less: On the development of knowledge of voicing and vowel alternations in German nouns by 5 year-olds, 7 year-olds and adults. In A. Biller, E. Chung, & A. Kimball (Eds.), *Proceedings of the 36th Boston University Conference on Language Development*. Vol. *2* (pp. 660–672). Boston, MA: Cascadilla Press.

Walker, R. (2011). *Vowel patterns in language*. Cambridge, England: Cambridge University Press.

Walker, R. (2012). Vowel harmony in optimality theory. *Language and Linguistics Compass*, *6*(9), 575–592.

Wiese, R. (1996). *The phonology of German*. New York: Oxford University Press.

Wilson, C. (2003). Experimental investigation of phonological naturalness. In G. Garding & M. Tsujimura (Eds.), *Proceedings of the 22nd West Coast Conference on Formal Linguistics*. Vol. *22* (pp. 533–546). Somerville, MA: Cascadilla Press.

Wilson, C. (2006). Learning phonology with substantive bias: An experimental and computational study of velar palatalization. *Cognitive Science*, *30*(5), 945–982.

Wonnacott, E., & Newport, E. (2005). Novelty and regularization: The effect of novel instances on rule formation. In A. Brugos, M. Clark-Cotton, & S. Ha (Eds.), *Proceedings of the 29th Boston University Conference on Language Development*. Vol. *2* (pp. 663–673). Boston, MA: Cascadilla Press.

Zamuner, T., Kerkhoff, A., & Fikkert, P. (2012). Phonotactics and morphophonology in early child language: Evidence from Dutch. *Applied Psycholinguistics*, *33*(3), 481–499.

Zhang, J., & Lai, Y. (2010). Testing the role of phonetic naturalness in Mandarin tone sandhi. *Phonology*, *27* (1), 153–201.

Zonneveld, W. (1978). *A formal theory of exceptions in generative phonology*. Vol. *1*. Lisse: Peter de Ridder Press.

Zonneveld, W. (1980). Hungarian vowel harmony and the theory of exceptions in generative phonology. *Linguistic Analysis*, *6*(1), 21–39.

Zsiga, E. (2013). *The sounds of language. An introduction to phonetics and phonology*. Chichester, England: Wiley-Blackwell.

Zuraw, K. (2000). *Patterned exceptions in phonology*. Ph.D. thesis, University of California.

Zuraw, K. (2007). The role of phonetic knowledge in phonological patterning: Corpus and survey evidence from Tagalog infixation. *Language*, *83*, 277–316.

Appendix

Table A1
VH training items: Singular ~ plural

Stem Vowel is [−back]			Stem Vowel is [+back]		
ɪ	e	œ	o	ɔ	ʊ
mɪt ~ mɪty	met ~ mety	mœt ~ mœty	mot ~ motu	mɔt ~ mɔtu	mʊt ~ mʊtu
mɪʃ ~ mɪʃy	meʃ ~ meʃy	mœʃ ~ mœʃy	moʃ ~ moʃu	mɔʃ ~ mɔʃu	mʊf ~ mʊfu
mɪŋ ~ mɪŋy		mœŋ ~ mœŋy		mɔŋ ~ mɔŋu	mʊŋ ~ mʊŋu
nɪt ~ nɪty	net~ nety	nœt ~ nœty	not ~ notu	nɔt ~ nɔtu	nʊt ~ nʊtu
nɪʃ ~ nɪʃy	neʃ ~ neʃy	nœʃ ~ nœʃy	noʃ ~ noʃu	nɔʃ ~ nɔʃu	nʊʃ ~ nʊʃu
nɪŋ ~ nɪŋy		nœŋ ~ nœŋy		nɔŋ ~ nɔŋu	nʊŋ ~ nʊŋu
jɪt ~ jɪty	jet ~ jety	jœt ~ jœty	jot ~ jotu	jɔt ~ jɔtu	jʊt ~ jʊtu
jɪʃ ~ jɪʃy	jeʃ ~ jeʃy	jœʃ ~ jœʃy	joʃ ~ joʃu	jɔʃ ~ jɔʃu	jʊʃ ~ jʊʃu
jɪŋ ~ jɪŋy		jœŋ ~ jœŋy		jɔŋ ~ jɔŋu	jʊŋ ~ jʊŋu
lɪt ~ lɪty	let ~ lety	lœt ~ lœty	lot ~ lotu	lɔt ~ lɔtu	lʊt ~ lʊtu
lɪʃ ~ lɪʃy	leʃ ~ leʃy	lœʃ ~ lœʃy	loʃ ~ loʃu	lɔʃ ~ lɔʃu	lʊʃ ~ lʊʃu
lɪŋ ~ lɪŋy		lœŋ ~ lœŋy		Iɔŋ ~ lɔŋu	lʊŋ ~ lʊŋu
fɪt ~ fɪty	fet ~ fety	fœt ~ fœty	fot ~ fotu	fɔt ~ fɔtu	fʊt ~ fʊtu
fɪʃ ~ fɪʃy	feʃ ~ feʃy	fœʃ ~ fœʃy	foʃ ~ foʃu	fɔʃ ~ fɔʃu	fʊʃ ~ fʊʃu
fɪŋ ~ fɪŋy		fœŋ ~ fœŋy		fɔŋ ~ fɔŋu	fʊŋ ~ fʊŋu
dɪt ~ dɪty	det ~ dety	dœt ~ dœty	dot ~ dotu	dɔt ~ dɔtu	dʊt ~ dʊtu
dɪʃ ~ dɪʃy	deʃ ~ deʃy	dœʃ ~ dœʃy	doʃ ~ doʃu	dɔʃ~ dɔʃu	dʊʃ ~ dʊʃu
dɪŋ ~ dɪŋy		dœŋ ~ dœŋy		dɔŋ ~ dɔŋu	dʊŋ ~ dʊŋu
kɪt ~ kɪty	ket ~ kety	kœt ~ kœty	kot ~ kotu	kɔt ~ kɔtu	kʊt ~ kʊtu
kɪʃ ~ kɪʃy	keʃ ~ keʃy	kœʃ ~ kœʃy	koʃ ~ koʃu	kɔʃ ~ kɔʃu	kʊʃ ~ kʊʃu
kɪŋ ~ kɪŋy		kœŋ ~ kœŋy		kɔŋ ~ kɔŋu	kʊŋ ~ kʊŋu
zɪt ~ zɪty	zet ~ zety	zœt ~ zœty	zot ~ zotu	zɔt ~ zɔtu	zʊt ~ zʊtu
zɪʃ ~ zɪʃy	zeʃ ~ zeʃy	zœʃ ~ zœʃy	zoʃ ~ zoʃu	zɔʃ ~ zɔʃu	zʊʃ ~ zʊʃu
zɪŋ ~ zɪŋy		zœŋ ~ zœŋy		zɔŋ ~ zɔŋu	zʊŋ ~ zʊŋu

Table A2
AV training items: Singular ~ plural

Stem Vowel is [lax]			Stem Vowel is [tense]		
ɪ	ʊ	œ	o	e	a
mɪt ~ mɪty	mʊt ~ mʊty	mœt ~ mœty	mot ~ motu	met ~ metu	mat ~ matu
mɪʃ ~ mɪʃy	mʊʃ ~ mʊʃy	mœʃ ~ mœʃy	moʃ ~ moʃu	meʃ ~ meʃu	maʃ ~ maʃu
mɪm ~ mɪmy	mʊm ~ mʊmy		mom ~ momu		mam ~ mamu
nɪt ~ nɪty	nʊt ~ nʊty	nœt ~ nœty	not ~ notu	net ~ netu	nat ~ natu
nɪʃ ~ nɪʃy	nʊʃ ~ nʊʃy	nœʃ ~ nœʃy	noʃ ~ noʃu	neʃ ~ neʃu	naʃ ~ naʃu
nɪm ~ nɪmy	nʊm ~ nʊmy		nom ~ nomu		nam ~ namu
jɪt ~ jɪty	jʊt ~ jʊty	jœt ~ jœty	jot ~ jotu	jet ~ jetu	jat ~ jatu
jɪʃ ~ jɪʃy	jʊʃ ~ jʊʃy	jœʃ ~ jœʃy	joʃ ~ joʃu	jeʃ ~ jeʃu	jaʃ ~ jaʃu
jɪm ~ jɪmy	jʊm ~ jʊmy		jom ~ jomu		jam ~ jamu
lɪt ~ lɪty	lʊt ~ lʊty	lœt ~ lœty	lot ~ lotu	let ~ letu	lat ~ latu
Iɪʃ ~ Iɪʃy	lʊʃ ~ lʊʃy	lœʃ ~ lœʃy	loʃ - loʃu	leʃ ~ leʃu	laʃ ~ laʃu
lɪm ~ lɪmy	lʊm ~ lʊmy		lom ~ lomu		lam ~ lamu
fɪt ~ fɪty	fʊt ~ fʊty	fœt ~ fœty	fot ~ fotu	fet ~ fetu	fat ~ fatu
fɪʃ ~ fɪʃy	fʊʃ ~ fʊʃy	fœʃ ~ fœʃy	foʃ - foʃu	feʃ ~ feʃu	faʃ ~ faʃu
fɪm ~ fɪmy	fʊm ~ fʊmy		fom ~ fomu		fam ~ famu
dɪt ~ dɪty	dʊt ~ dʊty	dœt ~ dœty	dot ~ dotu	det ~ detu	dat ~ datu
dɪʃ ~ dɪʃy	dʊʃ ~ dʊʃy	dœʃ ~ dœʃy	doʃ ~ doʃu	deʃ ~ deʃu	daʃ ~ daʃu
dɪm ~ dɪmy	dʊm ~ dʊmy		dom ~ domu		dam ~ damu
kɪt ~ kɪty	kʊt ~ kʊty	kœt ~ kœty	kot ~ kotu	ket ~ ketu	kat ~ katu
kɪʃ ~ kɪʃy	kʊʃ ~ kʊʃy	kœʃ ~ kœʃy	koʃ ~ koʃu	keʃ ~ keʃu	kaʃ ~ kaʃu
kɪm ~ kɪmy	kʊm ~ kʊmy		kom ~ komu		kam ~ kamu
zɪt ~ zɪty	zʊt ~ zʊty	zœt ~ zœty	zot ~ zotu	zet ~ zetu	zat ~ zatu
zɪʃ ~ zɪʃy	zʊʃ ~ zʊʃy	zœʃ ~ zœʃy	zoʃ ~ zoʃu	zeʃ ~ zeʃu	zaʃ ~ zaʃu
zɪm ~ zɪmy	zʊm ~ zʊmy		zom ~ zomu		zam ~ zamu

The AV rule states that a lax vowel triggers the [−back] vowel and a tense vowel triggers the [+back] vowel. For half the participants the counterrule held instead, in which a lax vowel triggers the [+back] vowel and a tense vowel triggers the [−back] vowel. This affected, of course, only the plurals. For the overview we only show the plurals of the first version of the AV rule.

Table A3
VH test items: Singular

Stem Vowel is [−back]			Stem Vowel is [+back]		
ɪ	e	œ	o	ɔ	ʊ
mɪs	mes	mœs	mos	mɔs	mʊs
mɪp	mep	mœp	mop	mɔp	mʊp
nɪs	nes	nœs	nos	nɔs	nʊs
nɪp	nep	nœp	nop	nɔp	nʊp
Jɪs	jes	jœs	jos	jɔs	jʊs
JɪP	jep	jœp	jop	jɔp	jʊp
lɪs	les	lœs	los	lɔs	lʊs
lɪp	lep	lœp	lop	lɔp	lʊp
fɪs	fes	fœs	fos	fɔs	fʊs
fɪp	fep	fœp	fop	fɔp	fʊp
dɪs	des	dœs	dos	dɔs	dʊs
dɪp	dep	dœp	dop	dɔp	dʊp
kɪs	kes	kœs	kos	kɔs	kʊs
kɪp	kep	kœp	kop	kɔp	kʊp
zɪs	zes	zœs	zos	zɔs	zʊs
zɪp	zep	zœp	zop	zɔp	zʊp

Table A4
AV test items: Singular

Stem Vowel is [lax]			Stem Vowel is [tense]		
ɪ	ʊ	œ	o	e	a
mɪs	mʊs	mœs	mos	mes	mas
mɪp	mʊp	mœp	mop	mep	map
nɪs	nʊs	nœs	nos	nes	nas
nɪp	nʊp	nœp	nop	nep	nap
jɪs	jʊs	jœs	jos	jes	jas
jɪp	jʊp	jœp	jop	jep	jap
lɪs	lʊs	lœs	los	les	las
lɪp	lʊp	lœp	lop	lep	lap
fɪs	fʊs	fœs	fos	fes	fas
fɪp	fʊp	fœp	fop	fep	fap
dɪs	dʊs	dœs	dos	des	das
dɪp	dʊp	dœp	dop	dep	dap
kɪs	kʊs	kœs	kos	kes	kas
kɪp	kʊp	kœp	kop	kep	kap
zɪs	zʊs	zœs	zos	zes	zas
zɪp	zʊp	zœp	zop	zep	zap