

German glide formation functionally viewed*

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Abstract

Glide formation, a process whereby an underlying high front vowel is realized as a palatal glide, is shown to occur only in unstressed prevocalic position in German, and to be blocked by specific surface restrictions such as *ji and *ɛj. Traditional descriptions of glide formation (including derivational as well as Optimality theoretic approaches) refer to the syllable in order to capture its conditions. The present study illustrates that glide formation (plus the distribution of long and short tense /i/) in German can better be captured in a Functional Phonology account (Boersma 1998) which makes reference to stress instead of the syllable and thus overcomes problems of former approaches.

1 Introduction

The present study on glide formation is restricted to the palatal glide /j/. German has no phonemic labiovelar glide [w], but phonetically this segment occurs as second part of the falling diphthong [aw] as in *grau* ‘grey’. Furthermore, some loanwords undergo a change of the form /u/ → [w], for instance *Guave* ‘guava’ [gu.¹a.və] can be realized as [ˈgwa.və] in fast speech. Since these processes are restricted to loanwords with sequences of /gu/ plus vowel, they are extremely rare and will be ignored in the following discussion.¹

The palatal glide in German is usually described as occurring in onset or coda position, as the examples in (1a) and (1b), respectively, illustrate (the IPA transcriptions are based on Muthmann 1996, with exceptions as elaborated in section 2 below). The glide does not occur in the syllable nucleus.

(1) a)	Joch	[jɔx]	‘yoke’	b)	drei	[dʁaj]	‘three’
	Koje	[ˈkoːjə]	‘bunk’		heute	[ˈhøj.tə]	‘today’
	Banjo	[ˈban.jo]	‘Banjo’		Zeitung	[ˈtsaj.tuŋ]	‘newspaper’

A syllabic high front tense vowel [i] in prevocalic position can be re-syllabified as the onset of a following syllable, and is then realized as a glide. Examples are given in (2).^{2,3,4}

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¹ The marginal status of the labio-velar approximant is reflected in the phonological dictionaries of German, which shows inconsistencies in the description of the possibly glided /u/: in Muthmann (1996), for instance, *Jaguar* ‘jaguar’ is listed with a glide (a non-syllabic vowel) [ˈja:ɡʷa:r], and *Pinguin* with a full vowel [ˈpɪŋɡwi:n].

² In German, a glottal stop is optionally inserted before a syllable-initial, stressed vowel (Hall 1992: 58f.). It can also be inserted before an unstressed morpheme-initial vowel, though less often than before a stressed one (Vater 1995: 96). The glottal stop is not included in the present transcriptions, unless it is of importance for the analysis, see section 3.

³ The syllabification in these and the following examples is based on Hall (1992, 2003).

(2)	Tiara	‘tiara’	[ti.ˈɑː.ra]	~	[ˈtjɑː.ra]
	Linie	‘line’	[ˈliː.ni.ə]	~	[ˈliː.njə]
	Indien	‘India’	[ˈɪn.di.ən]	~	[ˈɪn.djən]
	Ferien	‘holidays’	[ˈfɛ.ʁi.ən]	~	[ˈfɛʁ.jən]
	grandios	‘terrific’	[gʁan.di.ˈʊs]	~	[gʁan.ˈdjʊs]
	Gremium	‘panel’	[ˈgʁɛ.mi.ʊm]	~	[ˈgʁɛ.mjʊm]

This optional process will be referred to as *glide formation* in the present article, following Hall (1992, 2003) for German, and Rosenthal (1994) for other languages.

Some German words can only be pronounced with a glide though their orthographic representation shows an <i>, see the examples in (3).

(3)	Nation	‘nation’	[na.ˈtsjoːn]	*[na.tsi.ˈoːn]
	Union	‘union’	[u.ˈnjɔːn]	*[u.ni.ˈoːn]
	Familie	‘family’	[fa.ˈmiː.ljə]	*[fa.ˈmiː.li.ə]
	Flexion	‘inflexion’	[fle.ˈksjoːn]	*[fle.ksi.ˈoːn]
	Mission	‘mission’	[mi.ˈsjɔːn]	*[mi.si.ˈoːn]
	Skorpion	‘scorpio’	[skɔʁ.ˈpjɔːn]	*[skɔʁ.pi.ˈoːn]

Hall (1992: 169) points out that the glides in the words under (3) can be realized as vowels “but this is typically a spelling pronunciation”. Such words could be argued to have an underlying /i/ that undergoes glide formation, but since no related word forms exist with a vowel instead of the glide, the learner has no reason to assume anything else than an underlying glide (see section 2 for further arguments on the assumption of an underlying glide). The case is different for words like the ones in (4a). Though these are mainly pronounced with a glide, too, they have related forms that indicate a vowel – glide alternation, see (4b).

(4)	a) <i>word</i>	<i>gloss</i>	b) <i>related form</i>	<i>gloss</i>
	Studium	[ˈʃtuːdjʊm] ‘studies’	studieren	[ʃtu.ˈdiː.ʁən] ‘to study’
	Linie	[ˈliː.njə] ‘line’	liniiert	[liː.ni.ˈiːʁt] ‘ruled’
	Prämie	[ˈpʁɛ.mjə] ‘bonus’	prämiieren	[pʁɛ.ˈmiː.ʁən] ‘to award’

Due to this vowel – glide alternation, the forms in (4a) are assumed to have an underlying high front vowel that undergoes glide formation. Evidence for an underlying vowel for both forms (3a and b) is given by the fact that a pronunciation of the words in (4a) with a high front vowel is acceptable, whereas the word forms in (4b) cannot be pronounced with a glide.

Derivational approaches to glide formation include Steriade’s (1984) treatment of Romanian, where she describes gliding as a rule that turns the vowel with the feature [+syllabic] into a glide with the feature [–syllabic]. Steriade’s approach depends on an identical underlying representation of the glide and the vowel, with high vocoids not being specified for major class features (which would make a categorization as either vowel or consonant necessary). Derivational work on gliding in German includes Hall (1992) and

⁴ The two different r-realizations of the word *Ferien* are based on Kohler (1995: 157). The respective surface restriction on *rj* sequences in German is discussed in section 4.3 below.

Wiese (1996). Both assume that the glide and vowel have the same feature representation but are assigned different skeletal positions or syllable constituents. A common problem of these derivational approaches is that several levels of syllabification have to be assumed: first reference to the syllable is necessary to capture the conditions for gliding. After gliding occurs, a resyllabification has to take place, since the glide is no longer vocalic, i.e. a syllable-nucleus.

Optimality-Theoretic approaches (Prince & Smolensky 1993; henceforth: OT) can avoid the problem of an application of the gliding rule followed by a resyllabification algorithm. Instead, syllabification and the realization of the single segment (vowel or glide) are evaluated simultaneously. Rosenthal (1994) proposes an OT account for vowel gliding in which he refers to the suprasegmental unit of the mora: a vowel /i/ is parsed as a non-moraic glide [j]. In their underlying form, the glide and the vowel do not differ. Hall's (2003) brief treatment of vowel gliding in German follows Rosenthal's approach.

In contrast to the OT approaches by Rosenthal and Hall, the account presented in this article assumes that the high front vowel and palatal glide differ in their underlying featural specification: the vowel is specified with a feature [+long] that implements its longer duration compared to the glide that is specified as [-long]. According to this view, glide formation involves a change from the underlyingly specified [+long] segment to a surface [-long] segment, licensed by constraints that militate against redundant articulatory effort. Blocking of such a change occurs when the segment in question is stressed, which is ensured by a high-ranked constraint that requires faithfulness to [+long] in stressed segments.

The present article is structured in the following way. Section 2 introduces controversies in the phonological representation and phonetic transcription of the high front vowel and the palatal glide in German. In section 3 the traditional OT account of glide formation with reference to the mora is described, and its shortcomings are illustrated. In section 4 I present an alternative account in a Functional Phonological framework that is based on the phonetic durational difference between vowel and glide. The last section concludes.

2 Of allophones and phonemes, and their transcription

In the phonological literature on German it is often argued that every instance of the palatal glide can be derived from an underlying high front vowel /i/ (see Wurzel 1970, Hall 1992, 2003, Wiese 1996).⁵ This assumption is based on the fact that [i] and [j] are in complementary distribution; the glide occurs at the edges of the syllable, as illustrated in (1) above, whereas the vowel can occur in the syllable nucleus only. The allophonic view of the high front vocoids is problematic for the following reasons. Let us look at the two German words *Ion* 'ion' and *Joch* 'yoke'. The first one can be pronounced as either [i.ʰo:n] or [ʰjo:n] (though the latter only in very quick speech), the second only as [jɔx], not as *[i.ʰɔx]. If both of them were represented with an initial /i/, how could we account for the fact that this segment *has* to be glided in *Joch*, but can be optionally glided in *Ion*?⁶ Additional representational information besides phonological features had to be included in order to make this distinction. The same

⁵ Hall (1992: 134ff) and Wiese (1996: 237) actually assume an underlying lax vowel /ɪ/, from which all occurrences of the glide can be derived.

⁶ The presently chosen examples are not ideal, since German seems to have a restriction on glide formation that requires a resulting minimal prosodic word of two syllables, since gliding in words such as *Ion*, *Diät*, or *Spion* sounds odd.

observation led van Lessen Kloeke (1982: 36ff.) and Werner (1972: 47) to assume an underlying differentiation between the high front vocoids.

Furthermore, German glide formation is blocked from applying if a sequence of palatal glide and high front vowel would result, e.g. the word *liniiert* ‘ruled’ is realized as [li.ni.ˈi:ɐt] not *[li.ˈnʲi:ɐt]. Nevertheless, German words with *ji* sequences exist, for instance *injizieren* ‘to inject’ [in.ji.ˈtʰi:zɪ.ɐn]. As Hall (2003: 100) correctly points out, occurrence of the latter can only be accounted for if the glide is assumed to be present underlyingly.⁷ Glide formation, on the other hand, does not apply if a surface sequence *ji* would emerge, see also section 4.3 below. Based on these two arguments, the present article assumes an underlying difference between the high front vowel and the palatal glide. The exact nature of this featural difference is dealt with in section 4.1.

A further point for clarification in the topic of German vowel-glide alternations is the notation of the high front vocoids. Pronunciation dictionaries of German have the following conventions for the transcription of the glide /j/. For word- and syllable-initial instances, the symbol [j] is used, though mostly to denote a palatal fricative (a [j̥] in IPA notation), see for instance Muthmann (1996) and Mangold (2000). Glides in post-vocalic position, which form together with the preceding tautosyllabic vowel a diphthong (cf. 1b), are transcribed either as a plain [i] (Muthmann 1996), a shortened [i̠] (Mangold 2000 for <ei>), or even as [y] (Mangold 2000 for <eu>). The high front vowel that occurs in pre-vocalic position and might undergo glide formation is generally transcribed as [i̠], irrespective of whether glide formation is obligatory, as in *Spanien* [ˈʃpa:ni̠ən] ‘Spain’, or optional, as in *Spion* ‘spy’ [ʃpi̠o:n] (both Mangold 2000: 766 and 769, respectively). The same tradition can be found in the phonological literature on German, where a distinction is made between [i̠], an allophone of /i/ that underwent glide formation, and [j] or [j̥], which are used for the underlying glide (Hall 1992, Yu 1992: 107, Wiese 1996).

A common source of both the pronunciation dictionaries and the phonological descriptions for a surface distinction between underlying glides and vowels that underwent gliding is Moulton (1962: 65). He distinguishes [i̠] from [j] and gives the following examples (the transcription and indication of the stress in (5) is Moulton’s):⁸

(5) a) [i̠]		b) [j]	
[dá:l̠jə]	Dahlie	[táljə]	Taille
[ʃpá:ni̠ɐ]	Spanier	[ʃampá:njɐ]	Champagner
[famí:l̠jə]	Familie	[vaní:l̠jə]	Vanille
[bɪl̠jót]	Billion	[bɪljét]	Billet
[mɪl̠járdə]	Milliarde	[brɪljánt]	brillant

According to Moulton, the two realizations of the glide under (5) differ in their syllable-position: [j] occurs syllable-initial, and [i̠] as second member of an onset cluster. Obviously, this transcription is guided by spelling: those segments written with an <i> are represented as [i̠], whereas those that do not have an <i> in the orthography are represented as [j]. Neither Moulton nor the pronunciation dictionaries and phonological descriptions based on his work

⁷ Even though such words are marginal in German, as pointed out by T.A. Hall (p.c.), they make an underlying distinction between glide and vowel necessary.

⁸ Note that not all words in (5a) are examples for glided vowels: the glide in the forms [bɪl̠jót] and [mɪl̠járdə] is assumed to be underlying in the present approach since no alternating forms of these words with a vowel exist.

give an explanation on the phonetic realization of [i̥], the so-called ‘non-syllabic vowel’, and on how it differs from the glide [j].

Based on the lack of phonetic evidence for a difference between the glided vowel and the underlying glide in German, the present study discards of the symbol [i̥] and transcribes all glides (independent of their syllable position) as [j], including the second part of the diphthongs [ɔj] and [aj]. Possible allophones of the glide such as the palatal fricatives [j̥] and [ç] which occur after voiced and voiceless obstruents, respectively (Kohler 1995: 156), are not differentiated. For an overview and discussion of these allophones see Mücke (1998).

The correlations between the phonemes /i/ and /j/ and their relevant allophones in the traditional approaches elaborated above and in the present view are summarized in figure 1.

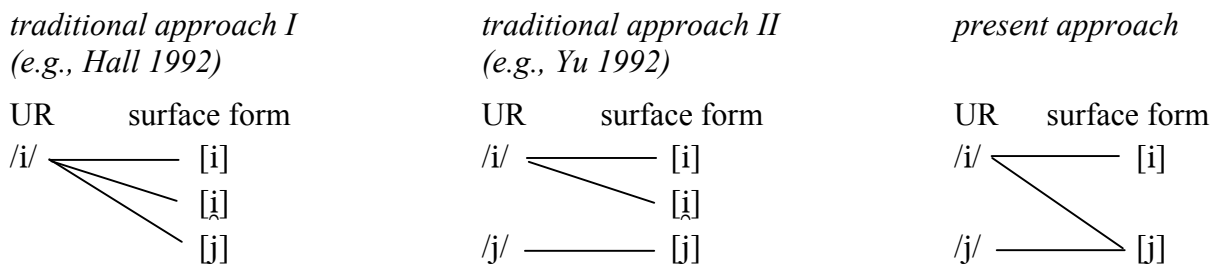


Figure 1 Three views on the phoneme /i/ and its glide allophone in relation to the phonetic realization of /j/.

In the proposal on the left of figure 1, made e.g. by Hall (1992) and Wiese (1996), a surface differentiation between vowel, glided vowel, and glide is made. All three stem from the same underlying high front vowel /i/. To determine the surface realization of the vowel, reference to its syllable-position is then necessary.

The second approach, represented by Yu (1992) and depicted in the middle of figure 1, assumes the same surface distinctions as the first proposal. However, these three surface forms are derived from two underlying representations: the surface glide stems from the underlying glide, whereas the vowel and glided vowel stem from the underlying vowel. Yu (1992: 109) proposes that the glided vowel and the underlying vowel have the same segmental features but are assigned different skeletal positions, with the glided vowel being dominated by a C and the unchanged vowel by a V, see figure 2.

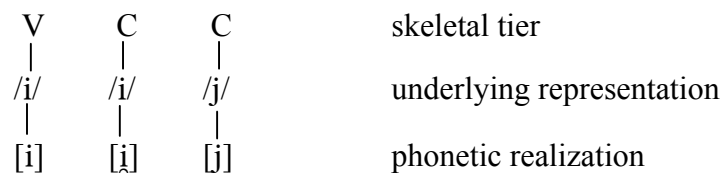


Figure 2 The three representations of vowel, glided vowel, and glide according to Yu (1992).

Two phonological tiers are thus necessary in Yu’s model to account for the surface contrasts of high vocoids in German.

The view taken in the present article (figure 1 right) is that of two underlying segments, glide and vowel, and of two surface realizations, either a vowel or a glide. As mentioned before, further allophones of the glide (such as [j̥] and [ç]) are not included, since they are not relevant for the present argumentation. In the context of glide formation, a

neutralization of glide and vowel occurs. The advantage of the present approach, which discards of syllable-related distinctions between glide realizations, is illustrated in section 4 below.

3 A syllable-based OT account of vowel gliding

The two traditional OT approaches to vowel gliding discussed here, namely Rosenthal (1994) for a large number of languages and Hall (2003) for German, have one point in common with generative descriptions (such as Steriade 1984); they treat vowel glide alternations as ‘a *result of syllabification*’ (Rosenthal 1994: 8; italics mine). Both analyses refer to the mora to account for vowel gliding: whereas the underlying vowel is moraic, the surfacing glide is non-moraic. Two constraints are necessary for such an analysis, a faithfulness constraint MAX-□, which preserves the underlying mora of the vowel (Itô 1986), cf. (6a), and a markedness constraint ONSET, which requires syllables to have onsets (Itô 1989, Prince & Smolensky 1993), cf. (6b). A change from vowel to glide is possible if one assumes that ONSET is higher ranked than MAX-□, as in (6c).

- (6) a) MAX-□: “A mora in the input corresponds to a mora in the output.”
- b) ONSET: “Syllables have to have an onset.”
- c) ONSET » MAX-□

The ranking in (6c) is proposed by Hall (2003) to account for glide formation in German. The word *Studium* is taken as example in tableau (7) to illustrate the analysis given by Hall:

(7)

/ʃtu:dium/	ONSET	MAX-□
[ʃtu:di.ʊm]	*!	
☞ [ʃtu:djʊm]		*

In this example, the second candidate, the one with the glide, wins because its second syllable has an onset (the glide). The first candidate has an onset-less second syllable and though it is most faithful to the underlying mora of the high vowel it loses due to its violation of the high-ranked ONSET constraint.

The tableau in (7) is missing an essential candidate, namely one with a glottal stop inserted between [ɪ] and [ʊ] (recall footnote 2 on the insertion of glottal stops in German). The candidate with a glottal stop is optimal with the present constraints, since it violates neither ONSET (all three syllables have an onset) nor MAX-□ (the vowel is not changed and thus the mora preserved). But as a new segment is inserted, this candidate would violate DEP (?), which militates against the insertion of a glottal stop. Ranking DEP (?) (or a general DEP) above MAX-□ secures the candidate with the glide to win, see (8).

(8)

/ʃtu:dium/	ONSET	DEP (?)	MAX-□
[ʃtu:di.ʊm]	*!		
☞ [ʃtu:djʊm]			*
[ʃtu:di.ʔʊm]		*!	

A candidate with a glottal stop therefore does not challenge the account proposed by Hall and Rosenthal.

However, there are problematic cases for the moraic OT approach. First, words like *naiv* ‘naive’ [na.i:f] with a stressed post-vocalic [i] are expected to undergo glide formation with the present constraints, since there is no constraint prohibiting a re-syllabification of the vowel as a coda, which is mora-preserving (though only one mora if an underlying long vowel is assumed). The candidate that should win is indicated by a ☺.

(9)

/nai:f/	ONSET	MAX-□
☺ [na.'i:f]	*!	
☹ ['najf]		*

Second, words like *Zion* ‘zion’ [tʰsi.ɔn] with a stressed pre-vocalic [i] are reduced to [tʰsjo:n] with the present constraints, since these constraints are insensitive to stress assignment:⁹

(10)

/tʰsi:ɔn/	ONSET	MAX-□
☺ [tʰsi:ɔn]	*!	
☹ [tʰsjo:n]		*

As these two examples show, the syllable-based account allows gliding of stressed high vowels because it does not take into account whether the vowels are stressed or not. A solution to this problem cannot be easily integrated in this approach, since the constraints used (ONSET and MAX-□) are syllabification constraints, only, which do not refer to stress. In the following section, a functional OT account is introduced that includes information on stress-assignment and therefore can avoid the problems discussed here.

4 A Functional Phonological account

Before presenting an alternative analysis of glide formation, we have to first determine the underlying representations of high front vowels and glides in the present framework. This will be done in section 4.1 below. Section 4.2 then offers an OT analysis. Section 4.3 deals with phonotactic restrictions that influence glide formation in German and their inclusion in the analysis, and section 4.4 is concerned with the optionality of gliding.

4.1 Underlying specifications and necessary constraints

The present study employs Boersma’s (1998 and following) Functional Phonology model (henceforth: FP) to account for the process of glide formation in German. A main contribution of FP to phonological theory is its distinction between a production, a perception, and a recognition grammar. Since we are primarily concerned with the production of glides and vowels, we will focus here on the production grammar.¹⁰ A further point of FP that strongly

⁹ The change in vowel quality and vowel length is obligatory in German for word-final stressed vowels, see Hall (2002a, b), and Hall & Hamann (2003), the latter show that this also holds for loanwords. The reader is referred to these sources for a formalization of the change in an OT framework.

¹⁰ The listener’s task of reconstructing the surface glide as underlying vowel could be of further interest for glide formation. This process is guided by the lexical knowledge of the listener and can be modelled by Boersma’s *recognition grammar*.

departs from traditional phonological approaches is the assumption of underlying *perceptual* features instead of articulatorily ones. In order to establish a perceptual feature that can be used to distinguish between high front vowels and palatal glides in German, we have to look at the perceptual and acoustic cues distinguishing the two segmental classes.

Maddieson and Emmorey (1985) compared the formant frequencies of the palatal glide and the high front vowel in Amharic, Yoruba, and Zuni. They found that in all three languages the glide has a lower first formant frequency than the vowel, and conclude from this that the glide is produced with a narrower constriction than the vowel. However, the recordings leading to this result include tokens of /i/ in palatal glide context only (in the nonsense word *iji*). As will be elaborated in section 4.3, the glide and maybe also the vowel in *ji* or *ij* sequences are expected to be articulated in a different way than in isolation or in other contexts, namely more consonantal-like for the glide (i.e., as a fricative) and more vowel-like for /i/ (i.e., as a mid front vowel) in order to manifest a greater difference between the two segments (perceptual reinforcement). Thus, the comparison of the high front vowel and palatal glide in exactly this context cannot reliably prove a difference in articulation.

Chitoran (2002, 2003) investigated the phonetic difference between the high front vowel [i] and the glide [j] in Romanian, and measured segmental duration, friction duration after the plosive [b], and the formant values at the starting point of both segments. The duration of the friction phase from plosive into the high vocoids was expected to be longer for the glide, indicating a narrower constriction. However, no significant differences could be found. Furthermore, Chitoran expected to find significant differences in the formant values at the beginning of the two segments. She found that the second formant was higher in the vowel for two of her three speakers. This is however no indication for a more narrow constriction in case of the glide, on the contrary. Chitoran (2003: 3016) interprets the lower F2 values for the glides as a ‘target undershoot’, which means that the glide is articulated with even less constriction than the vowel. The results of her studies show that only the difference in duration is a reliable cue for differentiating the two segments. Catford (1988: 67) also mentions duration as the only difference between the two high vocoids in English, and defines the palatal glide [j] as an ‘ultra-short [i]’.

Data on the articulatory difference between palatal glide and high front vowel in German is scarce. Wängler’s (1961) x-ray tracings of German [i:] and [j] of one speaker show that the two segments are articulated almost identically. The palatal glide [j] has a minimally longer constriction, i.e. the tongue front is raised a bit further than for the [i:]. Mücke (1997: 36f.) found in her acoustic investigation of the German high vocoids that both [i:] and [j] are voiced and have no frication intervocally, and that apart from a distinction in duration no other spectral differences could be present.

The present study takes the duration difference as the only reliable cue for differentiating between palatal glide and high front vowel in German. This difference of duration is represented as the abstract feature [long], with the vowel /i:/ being specified as [+long] and the glide /j/ as [–long], with otherwise identical features (the feature [long] is ternary, with the third value [0long] discussed below).

In the present approach the following phonetically based features are employed to distinguish German vowels: [low F1] and [mid F1] (standing for a low and mid first formant, respectively), and [low F2], [mid F2] and [high F2] (standing for a low, mid, and high second formant, respectively).¹¹ The specification of the German vowels with these features, based on

¹¹ The present account employs the features [low F1] and [mid F1] to account for the presence of more high and mid vowels than low vowels (vowel height is inversely related to the height of the first formant).

the average formant values of German vowels in Ramers (1988) and Heid et al. (1995), is given in (11).

(11)	i:/j	ɪ	y:	ʏ	u:	ʊ	e:	ɛ	ə	ø:	œ	o:	ɔ	ɑ:	a
[loF1]	+	+	+	+	+	+	-	-	-	+	+	-	-	-	-
[miF1]	-	+	-	+	-	+	+	+	+	+	-	+	-	-	-
[loF2]	-	-	-	-	+	+	-	-	-	-	-	+	+	+	-
[miF2]	-	-	+	+	-	-	-	+	+	+	+	-	-	+	+
[hiF2]	+	+	-	-	-	-	+	+	-	-	-	-	-	-	-

In the present analysis the long open-mid vowel [ɛ:], which Hall (1992) and Wiese (1996) assume to be a phoneme of German, is not included. I follow Moulton (1962), Sanders (1972), and Kohler (1995) who consider this sound a mere spelling pronunciation. Furthermore, I assume that the low vowels /a/ and /ɑ:/ differ not only in quality but also in quantity, see van Lessen Kloeke (1982).

In addition to the native phonemes in (11), German has the non-native vowels [i e y o ø]. These sounds differ from the respective long vowels exclusively in quantity. Since they occur in unstressed position only, whereas the long native vowels occur in stressed position, I assume that these non-native vowels are underlyingly identical to the long vowels, see Kohler (1999: 88). Their surface realization differs from the underlying specification in the feature long; the non-native tense vowels are [0long], i.e. of intermediate duration, as opposed to the long stressed vowels [+long] and the short glides [-long], see (12).

(12)	i:	i	j	y:	y	e:	e	o:	o	ø:	ø
[long]	+	0	-	+	0	+	0	+	0	+	0

The ternary feature [long] introduced here is not to be confused with Chomsky & Halle's (1968) binary feature [long], which was used to distinguish between underlyingly long and short vowels, only.

Within the present framework, a change from a vowel to a glide thus involves a featural change from [+long] to [-long]. Such a change militates against a perceptual faithfulness constraint, which Boersma (1998: 176f.) formulates as follows:

- (13) *REPLACE (*feature: value₁, value₂ / condition / left-env_right-env*):
 “Do not replace a specified value (*value₁*) on a perceptual tier (*feature*) with a different value (*value₂*), under a certain *condition* and in the environment *left-env* and *right-env*.”

Boersma's *REPLACE constraint family is similar to McCarthy & Prince's (1995) IDENT constraints. What IDENT fails to capture, however, is the possibility of gradual changes in feature values, and the fact that a small change is better accepted (i.e. causes fewer constraint violations) than the deletion of a whole feature plus the insertion of a new one.

For vowel gliding with the proposed underlying representations, a *REPLACE (long: +, -) constraint, or more mnemonic *REPLACE (i:, j), is necessary, which militates against a change from [+long] to [-long]. A change from underlying long to short vowel militates against the constraint *REPLACE (long: +, 0) or short *REPLACE (i:, i). Furthermore, the faithfulness constraint *REPLACE (long: +, Ø) or short *REPLACE (i:, Ø) militates against the

total deletion of the feature [long]. These three constraints are inherently ranked with respect to each other: Being faithful to a feature (though changing its feature value) is better than deleting the whole feature, therefore *REPLACE (i:, Ø) is ranked highest. The replacement of the feature value [+long] by [-long] is worse than its replacement by [0long], since the latter involves only one step along a scale of feature values, thus *REPLACE (i:, j) is higher ranked than *REPLACE (i:, i). The total ranking of these faithfulness constraints is given in (14).

(14) *REPLACE (i:, Ø) » *REPLACE (i:, j) » *REPLACE (i:, i)

As the present study is not concerned with the deletion of high front vowels, the high-ranked *REPLACE (i:, Ø) is not included in the following analysis.

The complementary distribution of the long high front vowel in stressed position and its short counterpart in unstressed position can be added to these faithfulness constraints via stress conditions. In general it can be stated that it is more important to be faithful to the percept of a segment in stressed position than in unstressed one.¹² For the faithfulness constraints *REPLACE (i:, j) and *REPLACE (i:, i) this looks as follows:

- (15) a) *REPLACE (i:, j / stressed):
 “Do not replace [+long] by [-long] when stressed.”
 b) *REPLACE (i:, j / unstressed):
 “Do not replace [+long] by [-long] when unstressed.”
 c) *REPLACE (i:, i / stressed):
 “Do not replace [+long] by [0long] when stressed.”
 d) *REPLACE (i:, i / unstressed):
 “Do not replace [+long] by [0long] when unstressed.”
 e) *REPLACE (i:, j / stressed) » *REPLACE (i:, i / stressed) » *REPLACE (i:, j / unstressed)
 » *REPLACE (i:, i / unstressed)

The constraint in (15a), which militates against the gliding of a stressed vowel, has a counterpart constraint (15b), which militates against the gliding of an unstressed vowel. Similar constraints against the shortening of the long high vowel are given in (15c) and (15d). The ranking as in (15e) emerges, with the *REPLACE constraints for stressed positions being higher ranked than those for unstressed positions.

Besides these faithfulness constraints, specific markedness constraints are necessary to account for glide formation. The high front vowel /i:/ requires a specific position of the tongue to be held for a certain duration (around 140 ms for a stressed /i:/ in German, see Ramers 1988: 197f.). The respective unstressed vowel requires the same position of the tongue for a shorter duration, and for the palatal glide an even shorter duration of the same gesture is required (unfortunately, no comparative data on the length of these three segments in German could be found). Thus both the shortening of /i:/ in unstressed position and its gliding can be motivated by a reduction of articulatory effort. This can be formulated by constraints of the *HOLD family (Boersma 1998: 150), as defined in (16).

- (16) *HOLD (*articulator: position, duration*):
 “An *articulator* stays at its neutral position, i.e., it is not held in any non-neutral *position* for any positive *duration*.”

¹² The present analysis is only concerned with primary stress. It has to be tested in future work whether the constraint in (15) refers to secondary stress, too. Words like *Biologe* ‘biologist’ [bi.ɔ.ˈloː.gə], with secondary stress on the first syllable, seem to allow gliding in fast speech: [bjɔ.ˈloː.gə], which indicates that gliding is not blocked by secondary stress.

To account for the articulation of a high front vowel a *HOLD (tongue: raised pre-dorsum, 140ms) constraint or short *HOLD (i:) is necessary. Similar *HOLD (i) and *HOLD (j) are needed. Since holding a gesture for 140 ms involves more effort than holding the same gesture for approximately 80 ms and 40 ms, respectively, the three constraints are universally ranked as in (17).

(17) *HOLD (i:) » *HOLD (i) » *HOLD (j)

The low ranked *HOLD (j) is irrelevant in the following analysis, and therefore not included. Since any change of the high front vowel /i:/ in *stressed* position is not allowed in German, *HOLD (i:) has to be ranked below the faithfulness constraints for the stressed vowel, see (18).

(18) *REPLACE (i:, j / stressed) » *REPLACE (i:, i / stressed) » *HOLD (i:) » *REPLACE (i:, j / unstressed) » *REPLACE (i:, i / unstressed)

In languages that do not allow *any* shortening or gliding of long high front vowels (whether stressed or unstressed), the *HOLD (i:) constraint is ranked below *REPLACE (i:, j / unstressed) or *REPLACE (i:, i / unstressed), respectively.

4.2 Analysis

With the constraints and the underlying specifications as elaborated in section 4.1, the gliding of the high front vowel in German can be formalized in a FP production grammar as in tableau (21). Before looking at this tableau in detail, some shorthand conventions have to be elaborated. In a FP production grammar, the input is the lexically stored perceptual representation of the word in question. This is represented in pipes *|spec|*. The output candidates that this form is compared to consist of two forms each, namely an articulatory and a corresponding perceptual form. The articulatory output is given in brackets [*art*] and the corresponding perceptual output in slashes */perc/*, all following Boersma (1998: 143ff.). Since a detailed transcription of both output forms is not necessary and might be confusing, we transcribe both forms in IPA notation. The reader has to be aware that the articulatory markedness constraints (e.g. *HOLD (i:)) tackle the articulatory form [*art*], whereas the perceptual faithfulness constraints (e.g. *REPLACE (i:, j)) refer to the corresponding perceptual form */perc/*.

The main stress of a lexical item is assumed to be underlyingly specified if it is irregular, and assigned via stress-specific constraints if regular. Since the present article is not concerned with stress-assignment in German, the reader is referred to Féry (1998) for an OT treatment of this topic and the relevant constraints. For simplicity, stress is indicated in the underlyingly specifications on the respective vowel.

First, the realization of the stressed long /i:/ with the present constraints is illustrated with the word *sie* ‘they’ [zi:], see tableau (19).

(19)

<i> z'i: </i>	*REPLACE (i:, j / stressed)	*REPLACE (i:, i / stressed)	*HOLD (i:)	*REPLACE (i:, j / unstressed)
[¹ zi] / ¹ zi/		*!		
☞ [¹ zi:] / ¹ zi:/			*	
[¹ zj] / ¹ zj/	*!			

Tableau (19) illustrates that neither shortening nor gliding of the *stressed* high front vowel is acceptable in German. Thus, the problematic cases for the syllabic OT account, namely *naiv*

and *Zion*, can be accounted for in the present proposal. Note that function words such as *sie* can undergo vowel shortening in unstressed position, because then they do not violate the *REPLACE (i:, i / stressed) constraint.

Next, the shortening of the high front vowel in unstressed position has to be dealt with. This is done in tableau (20) with the example *Titan* ‘titan’ /ti:ˈtɑ:n/. As the constraints on the stressed high vowel are not relevant for this and the following examples, they are not included.

(20)

	ti:ˈtɑ:n	*HOLD (i:)	*REPLACE (i:, j / unstressed)	*HOLD (i)	*REPLACE (i:, i / unstressed)
	[ti:ˈtɑ:n] /ti:ˈtɑ:n/	*!			
☞	[ti:ˈtɑ:n] /ti:ˈtɑ:n/			*	*
	[tj:ˈtɑ:n] /tj:ˈtɑ:n/		*!		

The ranking of the two constraints *HOLD (i) and *REPLACE (i:, i / unstressed) cannot be determined on the basis of this data.

With the constraints as defined up to now, however, the process of vowel gliding is predicted not to occur, as the example *Studium* in tableau (21) shows.

(21)

	ʃtˈu:di:ʊm	*HOLD (i:)	*REPLACE (i:, j / unstressed)	*HOLD (i)	*REPLACE (i:, i / unstressed)
	[ʃtu:di:ʊm] /ʃtu:di:ʊm/	*!			
☞	[ʃtu:di:ʊm] /ʃtu:di:ʊm/			*	*
⊗	[ʃtu:djʊm] /ʃtu:djʊm/		*!		

This ranking is problematic since *HOLD (i) is ranked below *REPLACE (i:, j / unstressed) which never allows any vowel gliding, but tableau (20) showed that exactly this ranking is necessary to block gliding of the unstressed vowel in words as *Titan*. What the FP constraints as defined up to now do not take into consideration is that gliding only takes place if another vowel is adjacent to the high front vowel, i.e. the environment of gliding is pre-vocalically (and possibly also post-vocalically).¹³ Thus words like *Studium* can undergo gliding whereas words like *Titan* cannot. Since the perceptual faithfulness constraint *REPLACE can include specific conditions, recall its definition in (13), the necessity for an adjacent vowel can be added to *REPLACE (i:, j / unstressed) as in (22a).

- (22) a) *REPLACE (i:, j / unstressed / C_C):
 “Do not replace [+long] by [–long] interconsonantly.”
 b) *REPLACE (i:, j / unstressed / C_C) » *REPLACE (i:, j / unstressed)
 c) *HOLD (i:) » *REPLACE (i:, j / unstressed / C_C) » *HOLD (i) » *REPLACE (i:, j / unstressed) » *REPLACE (i:, i / unstressed)

According to the elsewhere condition (Kiparsky 1973), the more restricted constraint in (22a) has to be ranked above the general constraint *REPLACE (i:, j / unstressed) introduced above,

¹³ Though not discussed in the phonological literature on German, optional gliding of post-vocalic high front vowels (i.e. formation of a falling diphthong) applies, too. The word *Koitus* ‘coitus’ [ˈko:i.tʊs], for instance, is acceptable with a realization as [ˈkɔj.tʊs] in quick speech, and so is the first name *Alois* [ˈa:lɔ.is] ~ [ˈa:lɔjs]. The fact that gliding can apply both to pre- and post-consonantal vowels, i.e. to onsets and codas, is a strong argument against the syllabic account presented in section 3.

as in (22b). Furthermore, the *HOLD (i) constraint is ranked below *REPLACE (i, j / C_C) because a reverse ranking gave vowel gliding even for interconsonantal /i:/. This results in the ranking in (22c).

With this modification of the *REPLACE constraints, both examples like *Studium* and *Titan* can be accounted for:

(23)

$ \text{ʃt'u:di:ʊm} $	*HOLD (i)	*REPLACE (i, j / unstressed / C_C)	*HOLD (i)	*REPLACE (i, j / unstressed)	*REPLACE (i, i / unstressed)
$[\text{ʃtu:.di:.ʊm}]/\text{ʃtu:.di:.ʊm}/$	*!				
$[\text{ʃtu:.di:.ʊm}]/\text{ʃtu:.di:.ʊm}/$			*!		*
$\text{☞} [\text{ʃtu:.dʒʊm}]/\text{ʃtu:.dʒʊm}/$				*	

(24)

$ \text{ti:t'a:n} $	*HOLD (i)	*REPLACE (i, j / unstressed / C_C)	*HOLD (i)	*REPLACE (i, j / unstressed)	*REPLACE (i, i / unstressed)
$[\text{ti:.'t'a:n}]/\text{ti:.'t'a:n}/$	*!				
$\text{☞} [\text{ti:.'t'a:n}]/\text{ti:.'t'a:n}/$			*		*
$[\text{tj:.'t'a:n}]/\text{tj:.'t'a:n}/$		*!		*	

In contrast to the traditional OT approach, where the insertion of a glottal stop satisfies the ONSET constraint and thus inclusion of an additional constraint (*DEP) is necessary to rule out a candidate with a glottal stop (that would otherwise be optimal), the present approach needs only the high-ranked constraint *HOLD (i) to ban *any* candidate with a fully realized vowel (with or without glottal stop).

It has to be mentioned here that vowel gliding is not restricted to high front vowels, or high vowels. As has been shown by Rosenthal (1994), languages such as Ilokano and Logo have a gliding process for mid vowels in addition to that of high vowels. German has some words that allow gliding of the mid front vowel [e] under the same conditions as elaborated above for the high front vowels, namely in unstressed position and adjacent to another vowel. Examples are *Lineal* ‘ruler’ [li.ne.'a:l], realized as [li.'nja:l] in colloquial German, and *ideal* ‘ideal’ [i.de.'a:l], also realized as [i.'dja:l]. The presented account can be transferred to gliding of the mid front vowel: this process is motivated by the articulatory markedness constraint *HOLD (e), which has to be higher ranked than *HOLD (j) in German to account for the glide output of the mid front vowel gliding.

4.3 Surface restrictions

Vowel gliding is blocked in two instances where specific surface restrictions in German would be violated. The first one involves words such as *Natrium* ‘sodium’, *Patriarch* ‘patriarch’, and *Triumph* ‘triumph’, where glide formation would yield a (tautosyllabic) sequence of (stop plus) *r* plus glide.

In a syllable-oriented OT approach such as Hall (2003), the non-gliding of these words can be captured by a phonotactic constraint * $_{\square}[\text{r}]$ that prohibits a sequence of (consonant plus) *r* plus *j* in onset position. See Hall (2002a) who proposes this constraint to account for a

phonotactic restriction in English, and Hall (1992: 171), who observes that *rj* sequences in German must be tautosyllabic. The constraints and their ranking necessary for a word such as *Natrium* not to undergo vowel gliding in a moraic OT account are given in tableau (25).

(25)

	/n'atrium/	* _σ [rj]	ONSET	MAX-σ
☞	[¹ na.tri.um]		*	
	[¹ na.trjum]	*!		*

In a functional, phonetically oriented approach, the restriction on the *rj* sequence does not have to refer to the syllable position, but can be formulated as a pure co-articulation restriction. It is impossible to pronounce a sequence of a velar fricative plus palatal glide, due to their different tongue configurations: the palatal glide involves a raising of the tongue front and a fronting of the tongue back, whereas the velar fricative involves a low tongue front and a retracted tongue back (see Hamann 2003 for a similar explanation for the co-occurrence restrictions on retroflex plus glide and retroflex plus front high vowel).¹⁴ The constraint in (26) is a formalization of this:

(26) *[ɤj]: “A sequence of velar fricative and glide is not pronounceable.”

Instead of the orthographic *r* that refers to any rhotic realization in German, the present constraint refers particularly to a velar fricative.¹⁵ The constraint in (26) is high-ranked in German. It is not necessary to refer to the syllable as domain for this constraint, since German does not have a [ɤj] sequence across syllable boundaries: the *r* sound is realized as a vocalic [ɐ] in coda position. The two possibilities of *r*-realization and syllabification (recall footnote 4) are illustrated with the first and third candidate of the word *Bakterie* ‘bacterium’ in tableau (27).

(27)

	bakt ¹ ɛɪi:ə	*[ɤj]	*HOLD (i)	*REPLACE (i, j / unstressed / C_C)	*HOLD (i)	*REPLACE (i, j / unstressed)
	[bak. ¹ te.ɪi:ə] /bak. ¹ te.ɪi:ə/		*!			
	[bak. ¹ te.ɪi.ə] /bak. ¹ te.ɪi.ə/				*!	
	[bak. ¹ te.ɤjə] /bak. ¹ te.ɤjə/	*!				
☞	[bak. ¹ teɐ.jə] /bak. ¹ teɐ.jə/					*

In the first candidate in (27), no glide formation applies, thus no *rj* sequence emerges. In the second candidate, the vowel is not glided but shortened, and thus militates against the *HOLD (i) constraint. Glides are formed in the third and fourth candidates, but whereas the third results in a [ɤj] sequence and thus violates the high ranked *[ɤj], the last candidate only violates the low ranked *REPLACE constraint. The last candidate realizes the underlying velar

¹⁴ Hall (2000b) gives a similar articulatory grounding for the non-occurrence of coronal rhotic plus palatal glide sequences.

¹⁵ The present account ignores variants of the velar fricative such as the velar trill, and variants of Standard German that have an apical trill instead of a velar rhotic. An articulatory restriction similar to (26) could account for such varieties.

fricative /ʁ/ as vowel [ø], which is a regular process in coda-position in German. The constraints accounting for this process are not included in the present analysis.

The second case of vowel gliding where an additional restriction is required concerns words which would result in a surface *ji* sequence, recall the discussions in section 2. An example is the word *liniirt* ‘ruled’ [li.ni.ˈi:ɐ̯t] which does not undergo vowel gliding, *[li.ˈnʝi:ɐ̯t]. To account for the blocking of glide formation if a [ji] sequence is to surface, we have to employ a constraint that is based on the fact that the two segments [i:] and [j] next to each other cannot be perceptually distinguished, since they are articulated in the same way and differ in length, only. Hall (2003) proposes a similar co-occurrence restriction. The presented constraint, see (28), does not only hold for long high front vowel plus glide but for any combination of high front vocoids.

(28) *[ji:/ ii:/ i:i:]: “A sequence of two high front vocoids cannot be perceptually parsed as such.”

Typological evidence for the constraint in (28), namely for the avoidance of palatal glide plus high front vowel sequences, comes from a large number of languages, for instance West Greenlandic (Fortescue 1984: 338) and Yucuna Aino (Schauer & Schauer 1967), which have no surface [ji] sequences. For an overview of languages and an elaboration of the phonetic explanation see Kawasaki (1982) (which deals also with the similarly motivated avoidance of [wu] sequences).

The constraint in (28) can be considered a kind of OCP restriction (Goldsmith 1976), because it militates against the surfacing of adjacent segments that are identical apart from their length specification. This constraint holds for *ii* sequences, too. German, however, seems to allow such sequences, as in the word *liniirt*. It is reasonable to assume that German speakers insert a glottal stop between the first and the second [i], in this and similar words, since the latter is stressed (recall footnote 2). The candidate [li.ni.ˈʔi:ɐ̯t], with the inserted glottal stop therefore does not violate the *[ji:/ ii:/ i:i:] constraint, as illustrated in tableau (29). (This tableau does not contain the constraint *REPLACE (i:, j / unstressed / C_C)).

(29)

	li.ni.ˈi:ɐ̯t	*HOLD (i)	*[ji:/ ii:/ i:i:]	*HOLD (i)	*REPLACE (i:, j / unstressed)
	[li.ni.ˈi:ɐ̯t] /li.ni.ˈi:ɐ̯t/	*!*	*		
	[li.ni.ˈi:ɐ̯t] /li.ni.ˈi:ɐ̯t/		*!	**	
☞	[li.ni.ˈʔi:ɐ̯t] /li.ni.ˈʔi:ɐ̯t/			**	
	[li.ˈnʝi:ɐ̯t] /li.ˈnʝi:ɐ̯t/		*!		

The ranking between *[ji:/ ii:/ i:i:] and *HOLD (i:) cannot be decided on the basis of these data. The tableau in (29) does not contain a faithfulness constraint against the insertion of the glottal stop (*REPLACE (Ø, ʔ)), which has to be ranked somewhere below the surface constraint *[ji:/ ii:/ i:i:] (its exact ranking cannot be decided on the basis of the present data alone).

Muthmann (1996: 331) lists an alternative pronunciation to *liniirt* [li.ni.ˈi:ɐ̯t] (the glottal stop is not specified in this source), namely one with only one *i*: [li.nˈi:ɐ̯t]. This candidate fares even better than the winning one in tableau (29). It violates neither the *[ji:/ ii:/ i:i:] constraint nor the *HOLD (i) constraint, because the unstressed [i] is dropped.

Despite the *[ji:/ ii:/ i:i:] constraint, German seems to allow homorganic glide-vowel sequences in words such as *injizieren* ‘to inject’ [in.ji.ˈtʰsi:.ʁən] or *Jieper* ‘craving’ [ˈji:.pɐ], where this sequence is specified underlyingly. I assume that speakers, in order to make the *ji* sequence perceivable, produce a fricative instead of the glide to distinguish it from the vowel, thus produce the sequence [j̥i] (this assumption still has to be phonetically tested). Evidence for such an assumption is given by Laver (1994: 298) who remarks that the articulatory starting point for [j] in *ji* sequences of English and the Chentu dialect of Chinese is normally slightly closer and fronter than for [i]. “The approximants in these positions in English and Chinese can thus act as auditorily distinctive syllable-onsets to the following vocoids” (Laver 1994: 299). Further evidence comes from the Melanesian language Tinrin, which is spoken in the southern part of New Caledonia. In Tinrin, the glide /j/ is realized as a voiced palatal approximant, according to Osumi (1995: 19). Osumi (ibid.) further notes that “when it [the glide] occurs before front vowels, it is pronounced with greater friction.” A similar observation was made for Lahu, a Tibeto-Burman language (Matisoff 1982).

The fricative articulation of the palatal glide in *ji* sequences can be modelled in an FP OT tableau as in (30), with a faithfulness constraint against the replacement of the glide by a fricative, *REPLACE (j, j̥), being lower ranked than the surface restriction *[ji:/ ii:/ i:i:]:

(30)

	ˈji:.pɐ	*[ji:/ ii:/ i:i:]	*REPLACE (j, j̥)	*HOLD (i:)	*HOLD (i)
	[ˈji:.pɐ] /ˈji:.pɐ/	*!		*	
☞	[ˈj̥i:.pɐ] /ˈj̥i:.pɐ/		*	*	
	[ˈji.pɐ] /ˈji.pɐ/	*!			*

This tableau shows that the perceptual markedness constraint *[ji:/ ii:/ i:i:] must be ranked above the perceptual faithfulness constraint *REPLACE (j, j̥) and the articulatory markedness constraint *HOLD (i:). The exact location of *REPLACE (j, j̥), however, cannot be determined with the present data.

4.4 Optionality

Up to now, nothing has been said in the analysis about the optionality of glide formation: the words under (2) were shown to be realizable either with glide or vowel. What happens then, if a speaker switches from a vowel realization to a glide realization, which usually goes together with a less formal register? In OT terms, such variability can be formalized as a reranking of constraints. In formal situations the *HOLD constraint hierarchy from (17) is demoted below the faithfulness constraint *REPLACE (i:, j / unstressed), see (31), because a faithful pronunciation is more important than saving articulatory effort. Note that *HOLD (i) has to stay ranked above the *REPLACE (i:, i / unstressed) constraint since vowel shortening in unstressed position is obligatory.

(31)

	ˈm̩di:ən	*REPLACE (i:, j / unstressed / C_C)	*REPLACE (i:, j / unstressed)	*HOLD (i:)	*HOLD (i)	*REPLACE (i:, i / unstressed)
	[ˈm̩.di:ən] /ˈm̩.di:ən/			*!		
☞	[ˈm̩.di.ən] /ˈm̩.di.ən/				*	*
	[ˈm̩.djən] /ˈm̩.djən/		*!			

In informal situations the *HOLD constraint hierarchy is promoted above the faithfulness constraints, see (32).

(32)

'm̩di:ən	*HOLD (i)	*HOLD (i)	*REPLACE (i, j / unstressed / C_C)	*REPLACE (i, j / unstressed)	*REPLACE (i, i / unstressed)
[l'm̩.di:ən] /l'm̩.di:ən/	*!				
[l'm̩.di.ən] /l'm̩.di.ən/		*!			*
☞ [l'm̩.djən] /l'm̩.djən/				*	

5 Conclusion

The present study showed that glide formation depends not on the syllable-position but on the stress-conditions of the glided vowel: gliding cannot occur with stressed vowels. This was illustrated to be problematic for OT approaches such as Rosenthal (1994) and Hall (2003) which employ only syllable-building constraints for glide formation. The OT FP account with underlying perceptual representations proposed here can avoid these problems by incorporating stress information directly in its perceptual faithfulness constraints: simply put, the percept of a stressed vowel is not allowed to be changed, whereas the percept of an unstressed vowel can be changed (at least slightly). The respective faithfulness constraints (*REPLACE (i, j / stressed) and *REPLACE (i, j / unstressed)), have a phonetically grounded fixed ranking (see (15e)). So do the markedness constraints (*HOLD) that motivate gliding, see (17). Different rankings between these two hierarchies can account for the optionality of vowel gliding.

In addition to optional glide formation, the same constraints can represent the obligatory process of high front vowel shortening, which is also not dependent on the syllable position but on stress: it only occurs in unstressed position.

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