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*Help or Hindrance: How Violation of Different Assimilation Rules Affects Spoken-Language Processing**

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KEY WORDS

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ABSTRACT

Four phoneme-detection studies tested the conclusion from recent research that spoken-language processing is inhibited by violation of obligatory assimilation processes in the listeners' native language. In Experiment 1, native listeners of German detected a target fricative in monosyllabic Dutch nonwords, half of which violated progressive German fricative place assimilation. In contrast to the earlier findings, listeners detected the fricative more quickly when assimilation was violated than when no violation occurred. This difference was not due to purely acoustic factors, since in Experiment 2 native Dutch listeners, presented with the same materials, showed no such effect. In Experiment 3, German listeners again detected the fricative more quickly when violation occurred in both monosyllabic and bisyllabic native nonwords, further ruling out explanations based on non-native input or on syllable structure. Finally Experiment 4 tested whether the direction in which the rule operates (progressive or regressive) controls the direction of the effect on phoneme detection responses. When regressive German place assimilation for nasals was violated, German listeners detected stops more slowly, exactly as had been observed in previous studies of regressive assimilation. It is argued that a combination of low expectations in progressive assimilation and novel popout causes facilitation of processing, whereas not fulfilling high expectations in regressive assimilation causes inhibition.

INTRODUCTION

The language input listeners have to process is far from consistent, not least because incoming continuous speech is subject to many phonological adjustment processes. Variation in length of phonemes, vowel reduction, elision of vowels, consonant and vowel epenthesis, reduction of consonant clusters, varying position of word stress and assimilation all occur constantly in spoken language. Despite all the variability, native listeners have little trouble in under-

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standing spoken language. They can accommodate to and even profit from rule-bound variation.

The present study focuses on the role in spoken-language processing of one type of phonological rule, namely assimilation. Assimilation is the process by which an inherent feature in a sound segment is altered under the coarticulatory influence of neighboring segments. The direction of assimilation can be regressive (i.e., a later segment affects an earlier one) or progressive (i.e., an earlier segment affects a later one) and is always an adjustment of the sound segment to its context. Rules of assimilation can be either optional or obligatory. If a rule is optional, both realizations, the adjusted and the unadjusted, are legal. If a rule is obligatory, there is only one legal standard realization. The English phrase *ten bikes* offers a site for optional regressive assimilation: the nasal can be realized in colloquial speech with a bilabial segment as [tɛm baɪks] and in more careful speech with an alveolar nasal as [tɛn baɪks]. The place feature of the bilabial stop can be spread to the preceding nasal. An example of optional progressive assimilation is found in the two possible realizations of the German word *leben* 'live' either as [le:bɪŋ] or as [le:bɪŋ] in more careful speech. In this case the place feature of the bilabial stop can be spread to the following nasal. In contrast, regressive place assimilation for nasals is obligatory in Japanese. The Japanese morpheme *san* 'three' occurs in many compound words: *sangatsu* 'March,' *sanban* 'third,' *sanju* 'thirty'. In the first of these the final nasal of the first syllable is realized as velar [ŋ], in the second as bilabial [m], in the third as dental-alveolar [n]. Place of articulation of the nasal differs as a function of the place of articulation of the following segment.

Recently a number of studies have investigated assimilation in Dutch, English, and Japanese, via phoneme-detection or word-recognition tasks (Gaskell & Marslen-Wilson, 1996; Gaskell & Marslen-Wilson, 1998; Koster, 1987; Kuijpers & Van Donselaar, in preparation; Otake, Yoneyama, Cutler, & Van der Lugt, 1996; Quené, Van Rossum, & Van Wijk, 1998). Those studies have shown a highly consistent pattern of results even though they were testing different languages and different assimilation rules and were using different experimental tasks. The results showed that spoken-language processing is neither facilitated nor interfered with by optional assimilation, but is inhibited by violation of obligatory assimilation.

For English, Koster (1987) investigated optional regressive place assimilation. Regressive place assimilation in English occurs optionally between morphemes in connected speech. The alveolar stop /t/ in *sweet girl* is either maintained or takes over the velar feature of the subsequent stop. The listeners' task was to press a button as soon as they heard the velar stop /g/ in [gɜ:l] (*girl*).¹ Koster did not find any evidence for exploitation of place cues in assimilated words: listeners were equally fast in detecting /g/ in [gɜ:l] after [swit] or [swik]. Thus, if assimilation is optional, speed of detection is unaffected by whether or not an immediately preceding consonant is assimilated to the target segment.

Gaskell and Marslen-Wilson (1996) investigated effects of place assimilation in English on the recognition of spoken words. They used a cross-modal repetition priming paradigm for their first experiments. English subjects listened to sentences that were

¹ Throughout this article, all examples and allophonic variants will be transcribed phonetically. Phonemes will be transcribed in slashes.

truncated after a prime word, the last sound of which was either assimilated to the following removed word or not. If, for example, the prime word *wicked* was originally followed by the word *prank*, *wicked* was realized in one case as [wɪkɪb] and in a second as [wɪkɪd]. The word *prank* was cut off after recording. After hearing the truncated sentence, subjects had to make a lexical decision on the now visually presented target word *wicked*. Reactions to the visual targets were equally fast after assimilated or unassimilated auditory prime words. In a second experiment, listeners heard the complete sentence where the assimilated form [wɪkɪb] was either followed by *prank* where the feature change in [wɪkɪb] is phonologically viable or by *game* where the feature change is not viable. Word recognition was affected if the assimilated form was followed by the phonologically nonviable context: the lexical decision on the target word *wicked* was delayed. Recognition of spoken words was not affected by optional assimilation but was impaired by inappropriately applied assimilation.

In a follow-up experiment Gaskell and Marslen-Wilson found similar effects with the phoneme-monitoring task (Gaskell & Marslen-Wilson, 1998). They investigated whether processing of the second segment interacted with the presence of the immediately preceding segment. Phoneme detection of the second segment was considerably slower when it occurred in a nonviable context (e.g., /k/ in *fun camp* realized as *[fʌm kæmp]) than when it occurred in an unchanged context (e.g., /k/ in [fʌn kæmp]), but there was no advantage for /k/ following viably assimilated segments ([fʌŋ kæmp]) over unchanged segments. Thus, inappropriate application of assimilation rules significantly slowed processing while lawful assimilation failed to facilitate it.

A similar result obtains for Dutch. Dutch allows optional voicing assimilation across obstruent sequences. Thus in Dutch the word *kaas* 'cheese' before *boer* 'monger' may be realized with a voiced fricative as [kaz.bu:r] instead of [kas.bu:r]. In a phoneme-monitoring task it was shown that voice assimilation did not facilitate recognition of the subsequent consonant /b/ (Kuijpers & Van Donselaar, in preparation). Dutch listeners detected the target segment equally fast in Dutch words whether the preceding segment was lawfully assimilated or unassimilated in an optional assimilation case. On the other hand, when the target is preceded by misapplication of assimilation, detection was significantly slowed. Dutch listeners found it harder to detect the target /p/ in *kaasplank* 'cheese board' if the fricative was voiced *[kaz.plʌŋk], than /p/ in [kas.plʌŋk] with an unvoiced fricative. The first form is not an assimilation environment, so that voicing in that position is inappropriate and consequently interfered with processing.

In Japanese, assimilation of place for a nasal and a following stop consonant is obligatory. The nasal must be homorganic with the following consonant in words like *tombo* 'dragonfly' where the moraic nasal is realized as bilabial [m] before the bilabial stop /b/ and in *kondo* 'this time' where the moraic nasal is alveolar before the stop consonant /d/. In the study of Otake et al. (1996) Japanese listeners responded equally rapidly and accurately to moraic nasals irrespective of their place of articulation. When asked to respond to the following stop, however, the same listeners were sensitive to the violation of the obligatory place assimilation. Their reaction times (RTs) in a phoneme monitoring task using real Japanese words were significantly slower in rule-violating items (heterorganic nasal and following stop consonant) than in lawfully assimilated items (homorganic nasal and following stop consonant).

Phonological adjustment processes, however, differ between languages. Listeners may use the phonological knowledge of their native language when listening to a non-native language. For instance the place assimilation rule for nasals tested by Otake et al. (1996) in Japanese is optional in certain environments in Dutch. In order to find out how the knowledge of one's native language affects the perception of spoken non-native languages, Otake et al. presented Dutch listeners with the same Japanese materials (which, for the Dutch listeners, were nonwords). These listeners, for whom assimilation of nasal-stop sequences is optional, showed no difference in their detection times for stop consonant targets preceded by nasals matched versus unmatched in place of articulation. For Dutch listeners no violation of their native phonology was involved.

Processing of a non-native language might, however, be influenced by violations of native language phonotactic constraints (even though the sequences are permissible in the language in which they were produced). Obligatory phonological rules of the native language of a listener may be violated when listening to a non-native language because these phonological rules do not apply in the non-native language. Although it can be argued that violation of assimilation rules is not usually encountered in native spoken language, it can occur in a non-native language. This situation is encountered by people learning a foreign language, or hearing someone speak their own language with a foreign accent. Listening to a non-native language which incorporates rules not valid for the native language appears to be no problem (see Otake et al., 1996), but what if the non-native language violates rules which do hold in the native language? Experiment 1 of the present study sought to examine whether phoneme detection during processing of a non-native language is sensitive to the violation of a native assimilation rule.

At the same time two other factors were changed relative to previous studies. The previous studies tested assimilation at least across a syllable boundary (see Otake et al., 1996), some even across a word boundary (see Gaskell & Marslen-Wilson, 1996; Gaskell & Marslen-Wilson, 1998; Koster, 1987; Kuijpers & Van Donselaar, in preparation). The reason for this may be that most studies have tested optional assimilation processes, and optional assimilation does not occur (in the languages tested) within a syllable. However, recent research in speech perception suggests that sublexical units such as the syllable can be crucial in speech segmentation and recognition (see Cutler, 1995 for a review). Therefore syllable structure may have had a crucial influence on previous findings. Thus far, how assimilation violation is processed in monosyllables has not been tested. Experiment 1 therefore uses monosyllables. A direct comparison between the processing of assimilation violation in monosyllables and bisyllables follows in Experiment 3.

Another constant factor thus far was the direction in which the assimilation rule operates. Previous experiments have only tested regressive assimilation. In regressive assimilation, a segment has an effect on the preceding segment, whereas in progressive assimilation a segment has an effect on the following segment. Both regressive and progressive assimilations form phonotactically legal segment strings, and violations of both types of assimilation result in phonotactically illegal sequences. But regressive and progressive assimilation contexts differ in the kind of expectations that they can induce in listeners.

In any phonological sequence, the set of possible later segments is always restricted, to greater or lesser extent, by the sequential phonotactics of the language. For any two-segment string, for example, listeners can therefore develop expectations about what the second

segment will be on the basis of the information they hear in the first segment. A regressive assimilation rule imposes strong constraints on these expectations, by limiting the set of possible continuations in a specific way. Under Japanese regressive place assimilation, for example, if the segment following a bilabial nasal consonant is a stop, it must also be bilabial. A violation of regressive assimilation thus results in a violation of these expectations; a segment that was not a member of the small set of expected continuations is heard. Progressive assimilation, on the other hand, does not act to impose particular limits on the set of possible continuations; instead, it acts to specifically exclude certain continuations. Under German progressive fricative assimilation, for example, the velar fricative is explicitly ruled out after front vowels (see below). Violation of progressive assimilation therefore results in a different kind of violation of the expectations set up by the first sound in a two-segment sequence; a segment that is a member of a small set of impossible continuations is heard.

As already noted, inhibition effects have been shown in previous experiments when listeners' expectations about an upcoming segment were defeated in regressive-assimilation violations. Given that progressive assimilation constrains the set of possible continuations in a different way to regressive assimilation, one can ask whether the defeat of the expectations caused by progressive assimilation will also result in an inhibition effect. The present experiments addressed this issue. Experiments 1, 2, and 3 tested a progressive assimilation rule. Experiment 4 tested a regressive assimilation rule.

In the first experiment of the present study, listeners were presented with non-native language input, in which a progressive native assimilation rule was violated within syllables. Two closely related languages were used: Dutch and German. The distribution of the palatal fricative [ç] and the velar fricative [x] in standard German provided the phonological background. Many phonologists, including Trubetzkoy (1939) and Wurzel (1980) have discussed these two allophonic variants, the distribution of which is predictable. The two fricatives stand in complementary distribution in German: the velar fricative [x] occurs after back vowels, the palatal fricative [ç] after front vowels, glides, sonorant consonants, word-initially and in the diminutive suffix *-chen* (see Hall, 1989, among many others). Thus the place of articulation of a vowel specifies the place of articulation for the following fricative (progressive assimilation).² Whereas German *lacht* 'laughs' is realized as [laxt] with a velar fricative due to the preceding back vowel, German *Licht* 'light' is realized as [lɪçt] with a palatal fricative due to the preceding front vowel. It would violate German fricative assimilation to realize the German word *Licht* as *[lɪxt] with a velar fricative and would result in the illegal sequence *[lɪx].

This distribution does not apply for standard Dutch, since the Dutch phoneme repertoire contains only the velar form of the fricative (Booij, 1995).³ Dutch *lacht* 'laughs'

² The suffix *-chen* is an exception, as preceding vowel quality does not affect the fricative in this case, but the fricative is conditioned by a morpheme boundary. This leads to a few apparent minimal pairs, such as [ku:xən] (*Kuchen* 'cake') and [ku:çən] (*Kuhchen* 'small cow').

³ Gussenhoven (1992) has pointed out that in some varieties of Dutch a postvelar or uvular fricative [χ] rather than the velar form occurs. For German, Kohler (1990) found variation between [x] and [χ] after some back vowels. However, the velar fricative [x] is possible in both standard German and Dutch.

and Dutch *licht* 'light' are both realized with a velar fricative in postvocalic word position as [laxt] and [lɪxt], regardless of the place of articulation of the preceding vowel. These different distributions make it possible to use German and Dutch to ask whether the native phonological structure influences processing of a non-native language. When German listeners attend to Dutch, they hear repeated violations of German fricative assimilation. Do German listeners show an inhibition effect (as observed in the other assimilation studies) when they are listening to Dutch items which violate obligatory German progressive fricative assimilation within syllables?

The generalized phoneme monitoring procedure (Segui & Frauenfelder, 1986), in which a predetermined target segment can occur anywhere in the stimulus, was chosen as the experimental task. Phoneme monitoring involves two tasks for the subjects, listening to speech and detecting a predetermined target segment (for an overview see Connine & Titone, 1997). The measured response times are assumed to reflect variations in speech processing, where longer RTs are associated with greater processing load.

Two types of phonotactically legal Dutch monosyllables were examined. All were nonwords both in German and in Dutch to avoid any potential lexical effects from cognates across the closely related languages. One type of monosyllable contained a front vowel followed by the velar fricative [x] in penultimate position (e.g., [bɛxt]). The other type contained a back vowel followed by the velar fricative [x] in penultimate position (e.g., [bɑxt]). The nonwords with back vowels were possible sequences in both standard Dutch and German. The nonwords with front vowels violated a German phonotactic constraint, but were legal in Dutch. In the first experiment German listeners were presented with the Dutch speech stimuli. Their task was to detect the target fricative [x] in the Dutch nonwords. An inhibition effect for violation of the German phonotactic constraint would show that listeners make use of their native phonological structure for phoneme recognition while listening to a non-native language.

EXPERIMENT 1

Method

Subjects

Twenty-four students of the University of Regensburg in Germany were paid to take part in the experiment. They were all native speakers of German and had no knowledge of Dutch.

Materials

A list of 28 monosyllabic items, nonwords in Dutch and German, was selected with the help of the CELEX database (Baayen, Piepenbrock, & Van Rijn, 1993). All items ended with the velar fricative [x] followed by the stop /t/, having the syllable structure CVxt or CCVxt (such as [hɔxt] and [frɪxt]). This syllable structure is common in both Dutch and German. No phonotactic constraints of either language, except the fricative assimilation in question, were violated in these nonwords. Only phonemes which occur in both languages were used, with one exception: the Dutch nonword '*wocht*' [vɔxt] is realized with a labiodental approximant, while in German it would be realized with a labiodental fricative (Booij, 1995; Wiese, 1996). The labiodental approximant does not occur in German. This small difference

was reckoned unlikely to have significant influence on processing. Fourteen of the chosen nonwords contained the front vowels /ε/ or /ɪ/, while 14 other nonwords contained the back vowels /a/ or /ɔ/. Only short vowels were used because short vowels predominate in closed syllables in German. Since all items had to be nonwords in both languages which violated no phonotactic constraints other than fricative assimilation, it was not possible to find 14 matched pairs of nonwords that differed only in the vowel. This was taken into account in the statistical analyses. The nonwords are listed in *Appendix 1*.

In addition, 308 mono- and bi-syllabic filler nonwords, also legal nonwords in both Dutch and German, were selected. Eighty-four of the fillers contained the fricative [x] in a variety of positions in the nonwords. All fillers contained one of the four vowels /ε/, /ɪ/, /a/ or /ɔ/. From the complete set of 336 items, four different pseudorandom orders were constructed, with the restriction that for at least two items before a target item, only fillers without the target fricative [x] were used. Fourteen similar practice items were created and presented at the beginning of the experiment. Three pauses were put in the experiment, one after the practice list and two more in the experiment itself, after every 112 items.

Procedure

All materials were recorded onto a DAT tape in a sound-proof booth by a female native speaker of Dutch, who also speaks German. The experimental stimulus nonwords were recorded two or three times and the best pronunciation was selected for use in the experiment. Although only phonemes that occur in both languages were used, there are of course phonetic differences especially in vowel quality between the two languages. Two native Dutch speakers listened to the materials and confirmed that they sounded Dutch. Speech stimuli were down-sampled during transfer to a computer to 16 kHz.

Each item was labeled using the Xwaves speech editor. Additionally, point labels were put in the experimental items at the beginning of the fricative [x]. Each nonword was then transferred as an individual speech file to the hard-disc of a personal computer. Stimulus presentation, timing, and data collection were performed using NESU experiment control software.

German subjects were tested one at a time in a sound-proof booth. They were told that they were to listen for the target fricative [x] in a series of Dutch nonwords, and they were instructed to press the button in front of them with their preferred hand as fast as possible if they detected [x] in any of the nonwords. Written instructions were given, telling the subjects to respond to the sound represented in orthography as *ch* as in the word *Nacht* 'night'. In German orthography both the velar and the palatal fricative are realized as *ch*. To make the task clear, additional oral instructions were given using German example words with the velar fricative only. Response times were measured from the onset of each target nonword. Each subject heard the practice list first, followed, after a short pause, by all experimental stimuli in one of the four pseudorandomized orders. The experiment lasted approximately 18 minutes.

Results and Discussion

Prior to statistical analysis, RTs, which were originally measured from the onset of the items, were adjusted so as to measure from the onset of the target fricative [x]. Missed

TABLE 1

Mean RTs (ms) and mean error rates for responses of German subjects to the penultimate velar fricative [x] after back or front vowels in monosyllabic Dutch nonwords

<i>Context</i>	<i>Back vowel</i> [baxt]	<i>Front vowel</i> *[bɛxt]
Mean	498	470
Error rate	0.8%	1.1%

responses were treated as errors. All RTs lay within the range of 100 to 1500ms. Mean RTs and mean error rates are given in Table 1.

Instead of responding more slowly, German subjects detected the fricative [x] 28 ms more quickly when the progressive German fricative assimilation rule was violated than when no violation occurred. Computed RTs were submitted to Analyses of Variance (ANOVAs), with both subjects (F_1) and items (F_2) as the repeated measure. The pattern in the RTs was significant by subjects, $F_1(1, 23)=4.82, p < .04$. By items, however, the effect did not reach significance, $F_2(1, 26)=3.01, p > .09$.

The reason why the items analysis failed to be significant was found in one of the illegal items. RTs to this particular item were on average 93 ms slower than RTs to the other 13 items in that context. Also this particular item showed the highest standard deviation. There was however a particularly slow item like this in the legal context as well. RTs to this item were on average 145 ms slower than RTs to the other 13 items in that context. Again, this particular item showed the highest standard deviation for its context. When both items were excluded, the mean RTs were 463 ms to illegal items and 488 ms to legal items. An analysis resulted in a significant effect of context for subjects and items, $F_1(1, 23)=6.69, p < .02$; $F_2(1, 24)=5.74, p < .03$. The low percentage of errors indicates that subjects had no problems detecting the target in the two types of nonwords. An error analysis revealed no significant main effect.

Whereas in all earlier studies violation of assimilation resulted in slower RTs (Gaskell & Marslen-Wilson, 1996; Gaskell & Marslen-Wilson, 1998; Koster, 1987; Kuipers & Van Donselaar, in preparation; Otake et al., 1996), RTs in Experiment 1 were faster to items containing such violations.

Why did this facilitation effect occur? The first and most obvious explanation was that some acoustic factors caused facilitation of processing rather than inhibition. Therefore an analysis of the duration of the target sound was performed. It is possible that RTs might be influenced by differences in the length of the presented target fricative, as length provides a simple measure of acoustic difference between targets across contexts. For the remaining 26 items (after excluding the two items with particularly slow RTs) the fricative [x] was on average 14 ms shorter after front vowels, with an average length of 177 ms, than after back vowels, with the average length of 191 ms, $t(12)=1.86, p > .07$. A correlation analysis with the RT data showed that there was no tendency for length to be correlated with RTs after both back and front vowels (after back vowels: $r(13)=.30, p > .3$; after front vowels: $r(13)=.23, p > .4$).

Since in Dutch the fricative does not assimilate to the preceding vowel, the vowel

might assimilate to the fricative instead. The velar fricative could have caused the preceding front vowel to have been produced lower and/or further back than elsewhere. This would be apparent in the first and the second formant of the front vowel. A comparison of F1 and F2 in target items such as [pɪxt] and [pɛxt] and fillers with the same vowels but no velar fricative such as [bɪft] and [blɛmp] showed no difference between the vowels before [x] and elsewhere. The formants were measured in the last third of the vowel and an inspection of the means of F1 and F2 for both front vowels in target items and fillers suggested that there was no lowering or backing in the target items compared to the fillers. Thus vowel quality could not have been a cue for the upcoming fricative.

Another way to test whether the results of Experiment 1 were due to acoustic confounds is to present the materials to subjects for whom they violate no rules: Dutch listeners. If the results of Experiment 1 are due to violation of phonological constraints, they should not replicate for subjects who lack the constraint. If, however, Dutch listeners showed a difference in their RTs, there might be unintended acoustic differences between the two sets of nonwords. Items had been chosen for Experiment 1 which were nonwords in both languages, German and Dutch. Once again the use of nonwords excluded lexical effects for both Dutch and for German listeners.

EXPERIMENT 2

Method

Subjects

Twenty-four native speakers of Dutch, students at the University of Nijmegen in the Netherlands, took part in the experiment. They were paid for their participation.

Materials

The same Dutch materials and the same lists as described in Experiment 1 were used.

Procedure

The same procedure as in Experiment 1 was used. The only difference was that for the Dutch subjects all the materials were legal Dutch nonwords that contained no phonological violation. The subjects were tested one, two, or three at a time in separate sound-proof booths. They were told that they would listen to Dutch nonwords. Instructions were given again in writing and orally using Dutch example words such as *nacht* 'night' and *geld* 'money' (the velar fricative can be realized in Dutch orthography both as *ch* and as *g*).

Results and Discussion

Mean RTs (from onset of the target fricative) and mean error rates are given in Table 2. Missed responses and one RT being slower than 1500ms were treated as errors.

For the Dutch subjects, listening to their native language, no phonological violation occurred in the materials. Accordingly, they showed no difference in their RTs between

TABLE 2

Mean RTs (ms) and mean error rates for responses of Dutch subjects to the penultimate velar fricative [x] after back or front vowels in monosyllabic Dutch nonwords

<i>Context</i>	<i>Back vowel</i> [baxt]	<i>Front vowel</i> [bæxt]
Mean	531	539
Error rate	2.1%	1.4%

the two types of monosyllabic nonwords. Whether a front vowel or a back vowel preceded the target fricative [x] made a difference of only 8 ms in the mean RTs of these subjects. The effect was, as expected, significant neither by subjects nor by items ($F_1, F_2 < 1$). Again, the low percentage of errors indicates that the subjects had no problems performing the task. An error analysis revealed no significant main effect.

Since the RTs of German listeners in Experiment 1 were faster than those of Dutch listeners in Experiment 2, a post hoc analysis was performed to check for the presence of interaction effects of language and context. A two factor mixed ANOVA was used, with language of the listener as the between subjects factor and context, with the two levels front and back vowel, as the repeated measures factor. Neither the main effect of language nor that of context reached significance by both subjects and items. The interaction of language and context did not quite reach significance either by subjects, $F_1(1, 46) = 3.71$, $p = .06$, or by items, $F_2(1, 26) = 3.30$, $p = .08$. A *t*-test showed that German listeners' reactions to the velar fricative [x] after a front vowel were significantly faster than Dutch listeners' reactions, $t_1(46) = 2.29$, $p < .03$; $t_2(13) = 5.82$, $p < .001$. After a back vowel no significant difference was found between the subject groups, $t_1(46) = 0.87$, $p > .3$; $t_2(13) = 2.11$, $p > .05$.

For all 28 items the fricative [x] was on average 15 ms shorter after front vowels, with an average length of 178 ms, than after back vowels with an average length of 193 ms, $t(13) = 2.14$, $p < .05$. For Dutch subjects there was a significant correlation between duration of the target fricative and RT after front vowels, $r(14) = .7$, $p < .01$; but none after back vowels, $r(14) = .34$, $p > .1$. An ANCOVA on the item RTs using target duration as a covariate, however, still found no effect of context, $F_2(1, 26) = 2.27$, $p > .1$.

The results of Experiment 2 indicate that there were no anomalies in the materials. RTs of Dutch subjects did not differ in responses to nonwords containing a front or a back vowel. It therefore remains to be explained why detection of a target segment which violated a German phonotactic constraint was facilitated for German listeners in Experiment 1 rather than inhibited as it was in previous studies (Gaskell & Marslen-Wilson, 1996; Gaskell & Marslen-Wilson, 1998; Koster, 1987; Kuijpers & Van Donselaar, in preparation; Otake et al., 1996). Three possibilities suggested themselves as sources for the facilitation effect. One was that the listeners were attending to non-native stimuli. The second possibility was the monosyllabic structure of the items. The third possibility was direction in which the tested rule operated. Experiments 3 and 4 examined these possibilities.

Although other studies have addressed how knowledge of the phonological structure

of one's native language affects the perception of spoken non-native languages (see e.g., Cutler, Mehler, Norris, & Segui, 1986; Otake et al., 1996), they have not looked at the effects of native assimilation rules on foreign language processing. In Otake et al. (1996), for example, Dutch listeners were presented with Japanese materials with place assimilation violations. Although the items violated obligatory Japanese place assimilation for nasals, they did not violate Dutch place assimilation rules (since the rule in Dutch is optional). Experiment 1 is therefore the first experiment in which a native assimilation rule was violated in non-native language materials. So it remains possible that the facilitation observed in Experiment 1 is due specifically to processes which operate when listeners are presented with non-native language. Violation of a native assimilation rule may cause facilitation when listening to a non-native language (as in Experiment 1), but not when listening to one's native language.

Experiment 3 therefore investigated the same German fricative assimilation in a phoneme-detection task with native speech stimuli. The German fricative assimilation rule was violated in similar nonwords, this time pronounced in German by a native speaker of German. Only German subjects were tested. The question was whether the facilitation effect found in non-native listening for violation of the German fricative assimilation would still be found when subjects were listening to their native language. Nonwords were used again for compatibility with Experiments 1 and 2.

Experiments 1 and 2 are the first to test violation of assimilation in monosyllables. To assess whether the findings of Experiment 1 might have been due to the monosyllabic structure of the experimental items, fricative assimilation was tested in both monosyllabic and bisyllabic items in Experiment 3. The monosyllabic items had the same structure as the nonwords used in Experiments 1 and 2. In the bisyllabic items the target fricative [x] occurred at the onset of the second syllable. So both the number of syllables and the position of the target sound within a syllable changed.

The German fricative assimilation rule applies across a syllable boundary if the first syllable ends in a vowel (i.e., if it is an open syllable). Whereas German *rauchen* 'smoke' is realized with a velar fricative as [rau.xən] due to the preceding back vowel, German *kriechen* 'crawl' is realized with a palatal fricative as [kri:çən] due to the preceding front vowel. The only exception to this rule is the diminutive suffix *-chen*, which is always realized with the palatal fricative [ç]. The diminutive form of *Frau* 'woman' is therefore realized with a palatal fricative as [frau.çən] even though the first syllable is open and ends with a back vowel. However, if the first syllable ends in a consonant (closed syllable), the second syllable must begin with the palatal fricative [ç] regardless of whether the vowel of the first syllable is back or front. German *hören* 'hear' as well as *München* 'Munich' are realized with the palatal fricative as [hɔr.çən] and [mʏn.çən].

To sum up, Experiment 3 was designed in part to investigate whether processing differences in non-native and native listening caused the facilitation effect for assimilation violation found in Experiment 1. The experiment also addressed whether syllable membership and preceding context influence this processing.

EXPERIMENT 3

Method

Subjects

Twenty-four students of the University of Regensburg took part in the experiment for a small payment. They were all native speakers of German. None of them had participated in Experiment 1.

Materials

The experiment was based very closely on Experiments 1 and 2. Again, a list of 28 monosyllabic items was selected with the help of the CELEX database. The same syllable structure and the same vowels as in Experiment 1 and 2 were used. This time the items (as German nonwords) only had to fulfill German constraints on word construction. As before, 14 of the nonwords with violation of assimilation contained the front vowels /ε/ or /ɪ/. Fourteen more nonwords with no violation contained the back vowels /a/, /ɔ/, or /ʊ/.

In addition to the 28 monosyllabic items, 28 bisyllabic items were selected. The bisyllabic items were also nonwords of German and also matched German constraints on word construction. The first syllable of half of the items had the closed syllable structure CVC or CCVC, where the vowel was either /ε/ or /ɪ/ and the syllable coda either of the sonorant consonants /n/ or /l/ (such as *[pɫɛnχən] or *[ʃpɪlχən]). The other half of the bisyllabic items had the open syllable structure CV or CCV in the first syllable with /u:/, /o:/, /a:/ or /au/ as its nucleus (such as [blu:χən]). The second syllable of all 28 bisyllabic items was either [χən] or [χər]. Items with a closed first syllable violated a German phonotactic constraint because the velar fricative [χ] appeared as a syllable onset following a closed syllable. Items with open first syllables contained no phonological violation. The items, forming 14 matched pairs each for mono- and bi-syllabic nonwords, are listed in *Appendix 2*.

A total of 254 filler nonwords were added to the materials. The filler material included both mono- and bi-syllabic nonwords. In 28 fillers the target fricative [χ] occurred at different positions across the nonwords. The palatal fricative [ç] never occurred. Fillers contained different German vowels, including all vowels used in the target items.

Four different pseudorandomized orders were constructed from the total set of 310 items. The items were constructed in such a way that each experimental item was preceded by at least one non target-bearing filler. Fourteen representative practice items were additionally created and were presented at the beginning of the experiment. There was a pause between the practice list and the experimental items.

Procedure

All materials were read by a female native speaker of German in a sound-proof booth and recorded on DAT tape. The speaker was also fluent in Dutch, which helped her to produce the velar [χ] after front vowels naturally.

All other details were as in Experiment 1 with one exception: digitized and labeled stimuli were transferred as individual speech files to four pseudorandomized lists and re-recorded on DAT for presentation.

TABLE 3

Mean RTs (ms) and mean error rates for responses of German subjects to the velar fricative [x] after back or front vowels in monosyllabic and bisyllabic German nonwords

Context	Monosyllabic		Bisyllabic	
	Back vowel [bɔxt]	Front vowel *[bixt]	Back vowel [blu:xən]	Front vowel *[blɪnxən]
Mean	513	488	535	497
Error rate	2.1%	1.5%	3.9%	2.4%

Subjects were tested one at a time in a sound-proof room. Instructions were given in the same manner as in Experiment 1, except that the subjects were told that they would hear German stimuli. Response times were measured from the onset of each target nonword. Each subject heard the practice list first, followed, after a short pause, by one of the four experimental lists. The experiment lasted about 16 minutes.

Results and Discussion

Prior to statistical analysis, RTs, which were originally measured from the onset of the items, were adjusted so as to measure from the onset of the target fricative [x]. Missed responses and one response to a monosyllabic item, which was slower than 1500 ms, were treated as errors. Mean RTs and mean error rates for the monosyllabic and bisyllabic nonwords are given in Table 3.

As in Experiment 1, German listeners detected [x] more quickly when a phonotactic constraint was violated than when no violation occurred. RTs of monosyllabic and bisyllabic items taken together were 524 ms in the legal context and 492 ms in the illegal context. A combined analysis with both monosyllabic and bisyllabic items showed that the difference in RTs was significant by subjects and by items, $F_1(1, 23) = 18.44, p < .001$; $F_2(1, 13) = 9.69, p = .004$. There was no interaction between number of syllables and context, $F_1, F_2 < 1$.

When evaluated separately, the difference in RTs for monosyllabic items was 25 ms. ANOVAs showed that this effect was significant by subjects, $F_1(1, 23) = 9.60, p = .005$, but not by items, $F_2(1, 13) = 2.91, p = .1$. For two of the 14 monosyllabic pairs of items, average RTs were considerably slower to the illegal item (by 50 ms in one case and 38 ms in the other), contrasting with the overall pattern. When both pairs of items were excluded from the ANOVA, there was a main effect of context for subjects and items, $F_1(1, 23) = 16.10, p = .001$; $F_2(1, 11) = 6.58, p < .03$. The mean RTs after exclusion of these items were 481 ms for illegal items and 519 ms for legal items.

For the remaining 12 monosyllabic pairs of items the duration of the target fricative was measured and was on average 14 ms shorter after front vowels, with an average length of 164 ms, than after back vowels, with an average length of 178 ms, $t(11) = 2.71, p < .02$. There was no significant correlation between duration of the fricative and RTs after either back vowels, $r(12) = .24, p > .5$, or front vowels, $r(12) = .48, p = .1$. An error analysis revealed no significant main effect.

Inspection of the means of the first and the second formant in target items with front

vowels and fillers with the same vowels but no velar fricative showed that there was no lowering or backing of the vowels before the velar fricative which could have functioned as a cue for the upcoming target fricative.

In bisyllabic nonwords listeners detected the target fricative [x] on average 38 ms faster when a phonotactic constraint was violated than when no such violation occurred. The difference was significant both by subjects and by items, $F_1(1, 23) = 11.43, p = .003$; $F_2(1, 13) = 7.03, p = .02$. An error analysis revealed no significant main effect.

Duration of the target fricative in the 14 bisyllabic pairs of items did not contribute to the effect. Average lengths of the target fricative after front and after back vowels were both 131 ms.

Since there were intervening consonants between the front vowels and the velar fricatives in the bisyllabic targets (/n/ or /l/), no lowering or backing of the front vowels was expected and therefore no comparison between first and second formant was done.⁴

Thus, if violation of assimilation occurred, a facilitation effect appeared in native and non-native listening, in mono- and bi-syllabic items, for target sounds in initial and penultimate position, and for target sounds preceded by either a vowel or a consonant. But so far facilitation for assimilation violation has been found only for German listeners, whereas inhibition was found for Japanese, Dutch, and English listeners. Another difference between the assimilation tested here and those in the previous literature lies in the direction in which the assimilation rule operates. German fricative assimilation operates progressively, whereas earlier experiments tested assimilation rules that operate regressively. Regressive assimilation narrows the number of legal second segments to a small set (few legal continuations), while progressive assimilation does not (many legal continuations) but rather explicitly excludes one certain continuation. Accordingly, listeners can have different kinds of expectations about the upcoming segment. The defeat of the expectations might be processed differently as a result. Is the facilitation effect for violation of assimilation due to the German fricative assimilation being progressive instead of regressive, or is it because the listeners are German? In Experiment 4, a German regressive assimilation rule was tested to investigate this question.

Place assimilation for nasals was chosen as the German regressive assimilation rule. This rule has been tested before for Japanese by Otake et al. (1996). Regressive place assimilation for nasals is seen as the spreading of the place feature of a stop to the preceding nasal (see Wiese, 1996), so that the nasal becomes homorganic with the following stop. Regressive place assimilation for nasals is obligatory within German syllables only for the velar stop /k/ and for the bilabial stop /p/: thus German *Bank* 'bank' must be realized as [baŋk] but not as *[bank] or *[bānk]. German *Lump* 'rogue' must be realized as [lʊmp] but not as *[lʊŋp] or *[lʊnp].

⁴ Another possibility was that subjects learned to detect the anomalous sequence in the course of the experiment. For Experiments 1, 2, and 3 the RTs were split up into four groups depending on the position of the corresponding item in the experiment. No significant interaction was found between position of the corresponding item in the experiment and context, with one exception: in the bisyllabic items in Experiment 3 an interaction suggested that listeners were learning to detect the fricative in the legal context, but not in the illegal context.

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In Experiment 4, German subjects had to detect either the target phoneme /k/ or the target phoneme /p/ in three different types of monosyllabic German nonwords. The experimental items were nonwords again, for comparison with Experiments 1, 2, and 3. They were monosyllabic because place assimilation for nasals in German is only obligatory within syllables. In one type of nonword, the stop was preceded by the correctly assimilated nasal, while in the two other types, the stops were preceded by two different unassimilated nasals. The German phoneme repertoire contains three nasals /n/, /ŋ/ and /m/ (which are distinctive in syllable final position).

EXPERIMENT 4

Method

Subjects

Forty-eight students from the University of Regensburg, all native speakers of German, were tested. They were paid for their participation. Twenty-four of the subjects had the target phoneme /k/; the other 24 had the target phoneme /p/.

Materials

A list of 84 monosyllabic items was selected with the help of the CELEX database (Baayen et al., 1993). All items were German nonwords, which were constructed of legal onset consonants and clusters, had a CVCC or CCVCC structure and contained short vowels only. Forty-two of the items ended in the velar stop /k/. In 14 of those the stop was preceded by the assimilated velar nasal /ŋ/ (such as in [fɛŋk]). Fourteen items violated the nasal place assimilation, in that /k/ was preceded by the alveolar nasal /n/ (such as in *[fɛŋk]). Fourteen more contained violations in that /k/ was preceded by the bilabial nasal /m/ (such as in *[fɛmk]). The other half of the 84 items ended in the bilabial stop /p/. In 14 of those nonwords the stop was preceded by the assimilated bilabial nasal /m/ (such as in [flɔmp]). Fourteen nonwords with the velar nasal /ŋ/ showed violation of assimilation (such as *[flɔŋp]). In the last 14 nonwords, also containing violation, the alveolar nasal /n/ occurred in penultimate position (such as in *[flɔnp]). Both for the nonwords ending in /k/ and for the nonwords ending in /p/ it was possible to find 14 matched triplets (see *Appendix 3*).

In addition 226 fillers were added to the materials, consisting of both mono- and bi-syllabic legal nonwords. In more than 200 items the target phonemes /k/ and /p/ did not occur. In the rest of the fillers the target phonemes occurred in a variety of positions in the nonwords. The three nasals /n/, /m/ and /ŋ/ occurred altogether 150 times in the fillers. The experimental items and the fillers were then used to construct four lists. Each list contained all 310 items in a different pseudorandom order, such that there was always at least one non-target-bearing filler before an experimental item. A list of 14 practice items was also constructed with similar materials, which was presented at the beginning of the experiment. As before, there was a pause between the practice list and the experimental list.

Procedure

All nonwords were recorded by the same female native speaker of German as in Experiment 3. The speaker was trained beforehand to produce the illegal sequences */nk/, */mk/, */np/ and */ŋp/ correctly in monosyllabic nonwords. Although experimental items were read two or three times and the best recording was chosen, in some items a short click sound was audible between the nasal and the stop. Epenthetic stops can appear in these environments because of mistiming of articulators (Ohala, 1995). This happened in four items containing the sequence */nk/, in four more items containing the sequence */mk/ and in five items containing the sequence */ŋp/. In order to avoid the possibility of subjects responding to these instead of the actual target stops, these clicks were removed by cutting them out of the nonwords. The spliced utterances were played to two native listeners of German who reported that they sounded as natural to them as unspliced utterances.

After digitizing the speech materials using Xwaves, the nonword boundaries and the release of the stops in the experimental items were labeled. As in Experiment 3, a portable computer with NESU experiment control software was used for the timing and data collection and stimuli were played from a DAT recorder over headphones.

Subjects were tested singly in a sound-proof room. The subjects with /k/ as target were asked to press the button in front of them with their preferred hand as fast as possible if they detected the target stop /k/, the other subjects were instructed to react to the target stop /p/. Response times were measured from the onset of each target nonword. Subjects heard the practice list first, followed after a short pause by one of the four experimental lists. The whole experiment lasted about 16 minutes.

Results and Discussion

As in Experiments 1, 2, and 3, RTs were adjusted so as to measure in Experiment 4 from the burst of the target phoneme. Missed responses and RTs outside the range of 100 to 1500 ms were again treated as errors. Altogether 13 responses were treated as errors because they lay outside the evaluated range of RTs. One subject who monitored for /p/ missed 67 of all stops. Since missed responses spread over all three types of nonwords, it was decided to exclude his RTs from the analysis. The results for phoneme detection of the velar stop /k/ and the bilabial stop /p/ are shown in Table 4.

Listeners detected the target stops more slowly when they were preceded by nonhomorganic nasals than when no violation occurred. A two factor mixed ANOVA was used, with the target stop as the between subjects factor and the nasal as the repeated measures factor. There was a highly significant main effect of nasal, $F_1(2, 90) = 17.68, p < .001$; $F_2(2, 52) = 10.46, p < .001$, but no main effect of stop was found.

Since both the bilabial and the velar nasal differ with respect to legality depending on the following stop (whereas the alveolar nasal does not), the factors nasal and target were expected to interact and indeed a highly significant interaction of nasal and target was found in the two factor mixed ANOVA, $F_1(2, 90) = 84.12, p < .001$; $F_2(2, 52) = 44.71, p < .001$.

For both target stops strong inhibition effects for violation of assimilation were observed when analyzed separately. With the repeated measures factor nasal as the only factor, RTs to both /k/ and /p/ still showed a highly significant main effect of preceding

TABLE 4

Mean RTs (ms) and mean error rates for responses of German subjects to the velar stop /k/ and /p/ after the three nasals /ŋ/, /n/ and /m/ in monosyllabic German nonwords

Context	/k/			/p/		
	[fɛŋk]	*[fɛnk]	*[fɛmk]	[flɔmp]	*[flɔnp]	*[flɔŋp]
Mean	435	500	516	366	490	532
Error rate	1.8%	4.2%	3.9%	4.0%	10.9%	7.8%

nasal (RTs to /k/: $F_1(2, 46)=21.78, p < .001$; $F_2(2, 26)=15.52, p < .001$; RTs to /p/: $F_1(2, 44)=75.44, p < .001$; $F_2(2, 26)=33.66, p < .001$).

An overall analysis of errors revealed a significant main effect of nasal by subjects but not by items, $F_1(2, 90)=4.25, p < .02$; $F_2(2, 52)=1.88, p > .1$. However, it also yielded a significant effect of stop, $F_1(1, 45)=7.53, p = .009$; $F_2(1, 26)=14, p = .001$. Separate analyses showed a significant effect of nasal by subjects for /p/, $F_1(2, 44)=5.79, p = .006$; $F_2(2, 26)=1.81, p > .1$, but not for /k/, $F_1(2, 46)=1.31, p > .2$; $F_2(2, 26)=1.77, p > .1$. Obviously subjects had some difficulty detecting the target stop /p/. This difficulty might partly be due to the fact that in German monosyllabic words ending with p-final clusters are much less frequent than monosyllabic words ending with k-final clusters. In addition, of the various stops /p/ is most likely to be confused with other nonstops because of weaker perceptual cues (Ohala, 1996).

Planned comparisons for the reaction time data and the error rates revealed the same effects as those found in the preceding analyses.

Overall neither the length of the target stop /k/ nor of the target stop /p/ were found to have contributed to the effects discovered. Although /k/ was longer after /m/ (131 ms) than after /ŋ/ (102 ms), $t(13)=2.91, p < .02$, or /n/ (107 ms), $t(13)=2.23, p < .05$, none of the contexts yielded a significant correlation of stop length with detection time. Similarly, although /p/ was longer after /ŋ/ (99 ms) than after /m/ (81 ms), $t(13)=2.80, p < .02$, with an intermediate length after /n/ (91 ms), target length did not correlate with detection time.

To sum up, Experiment 4 replicated the inhibiting effect of regressive assimilation violation found in earlier studies. German subjects detected the target stop /k/ or /p/ more slowly if the preceding nasal was not homorganic.

GENERAL DISCUSSION

The aim of the present study was to investigate how violation of different obligatory assimilation rules affects spoken-language processing. Previous research had consistently found an inhibition effect for processing violation of obligatory assimilation. But some aspects of assimilation were not examined in those studies. First, the effects of violating native assimilation rules in a non-native language were unknown. Second, assimilation had never been tested within syllables. Third, violations of progressive rather than regressive assimilation rules had never been tested. The present study therefore investigated the role of these factors in the processing of assimilation violations.

In Experiment 1, German listeners detected a target fricative in monosyllabic Dutch nonwords. When nonwords violated the obligatory German progressive fricative assimilation rule, a facilitation effect was found rather than an inhibition effect. For Dutch listeners, no native phonological violations were included in the target contexts, and accordingly in Experiment 2 they showed no effect of context in their reactions to the target fricative. The results of Experiments 1 and 2 are a confirmation of previous findings in the sense that the process of listening is language-specific. Earlier studies have already reported evidence that the process of listening in a non-native language is influenced by the native language of the listener (see e.g., Cutler et al., 1986; Otake et al., 1996).

Experiment 3 investigated whether the observed facilitation effect in Experiment 1 was due to the non-native listening task or to the monosyllabic structure of the tested items. The same German fricative assimilation rule was tested. German subjects again detected a target fricative in illegal German sequences more quickly, in both monosyllabic and bisyllabic items.

Experiment 4 showed that the necessary condition for facilitation in processing assimilation violations was the nature of the assimilation rule. Violations of regressive place assimilation for German nasals showed slower not faster RTs to stops in illegal segment strings. This matches the effect found in the previous literature for other languages (Gaskell & Marslen-Wilson, 1996; Gaskell & Marslen-Wilson, 1998; Koster, 1987; Kuijpers & Van Donselaar, in preparation; Otake et al., 1996).

Both regressive and progressive assimilation form phonotactically legal segment strings and violation of obligatory assimilation always results in phonotactically illegal segment strings. It is in both cases at the second involved segment that the sequence becomes illegal. So why does the violation make it easier in one case and harder in the other to recognize the second segment? Part of the answer to this question can be found in the different predictions which progressive and regressive assimilation make for the upcoming second segment, the monitoring target.

The phonotactics of German do not allow German listeners hearing the front vowels in Experiments 1 and 3 to have strong expectations for the next segment. For example /ε/ in /kε-/ could have been followed by /f/, /k/, /l/, /m/, /n/, /ŋ/, /p/, /r/, /s/, /ʃ/, /t/, or [ç]. Hearing /ε-/ however, excluded [x] as the following segment. Similarly, hearing /n/ or /l/ in syllable final position in the first syllable of bisyllabic items in Experiment 3 did not provoke strong expectations about the following syllable initial segment, but excluded [x]. The forward operating assimilatory effect weakly restricted what the following segment would be, while strongly excluding one certain segment.

In Experiment 4, on the other hand, German listeners hearing the velar nasal /ŋ/ could have strong expectations for the next segment. German phonology allows only a very restricted set of segments to follow the velar nasal in coda position. In /fεŋ-/ for instance, /ŋ/ could have been followed by only three consonants, /k/, /s/, and /t/. Thus, the regressive assimilatory effect strongly restricted what the following segment might be. This difference in set restriction effects is true for all segment strings that result from obligatory assimilation, at least in the tested languages.

Thus although both kinds of assimilation violations form phonotactically illegal sequences, progressive and regressive assimilation impose different kinds of constraints on

the second segment for the listener. Regressive assimilation results are the easier to explain. Here the listener has strong expectations as soon as the first segment is identified. Two tendencies could then be responsible for the present results. If the following legal segment can be predicted before it actually occurs, detection of the correct segment may be facilitated compared to the incorrect. Alternatively, when strong expectations are defeated by an illegal segment, inhibition of the unexpected item may result, as it does in visual attention experiments (Posner, Nissen, & Ogden, 1978).

For progressive assimilations, which defeat expectations, this explanation does not apply. Instead, the explanation seems to lie in another difference between the illegal sequences used here. Although both the illegal fricative and the illegal stop sequences have zero transitional probabilities within words, the latter type do occur across word boundaries (e.g., *dem Kamm* 'the comb'). The former do not: no German word begins with [x]. The fact that German listeners had never heard the sequence *[IX] before in their native language made this sequence a truly novel one for them. The difference between entirely novel sequences which never occur in any environment in the language and sequences which can occur in some environments in the language may be crucial.

Facilitation of processing for novel items is also reported in recent research on spontaneous visual attention; specifically, novel items are reported to cause rapid orientation (see also Christie & Klein, 1996). Johnston and colleagues have published several recent articles (Johnston & Schwarting, 1996; Johnston & Schwarting, 1997) on this phenomenon, which they have called "*novel popout*." They found that novel items were more accurately localizable than familiar items when observers had a glimpse of a scene but were not looking for anything in particular. Familiar items were visually-presented words that occurred frequently and thus were expected to occur in the experiment, whereas novel items were presented once and thus were not expected to occur in the experiment (novel items were therefore not novel in an absolute sense since they were existing words in the subjects' native language). According to Johnston, novel popout reflects the fact that novel items receive some sort of processing priority and that this is an important adaptive process that has evolved in early phylogenetic history (Johnston & Schwarting, 1997).

This adaptive process might explain why listeners in the present study were faster in their detection of the target fricative (not absolutely novel by itself) if it occurred in a sequence which was truly novel for the listeners. Listeners could not have had strong expectations about which segment would follow the front vowel /ɪ/ in Experiments 1 and 3, but since the following segment [x] was completely new for them in that context it stood out. A number of subjects even reported after the experiment that the target fricative sometimes "popped out." It appears to be the combination of weak expectations and the novel popout effect that facilitated processing in Experiments 1 and 3. When a particular second segment is strongly expected, novelty alone does yield facilitation, as the Japanese experiments on violation of assimilation showed (Otake et al., 1996). In Japanese, nasals never mismatch in place of articulation with a following stop, not even across word boundaries (Vance, 1987). Therefore Japanese listeners have, for example, never heard the sequence */mk/ in their native language. After hearing /m/ they very strongly expected a labial to follow and this expectation might have outweighed any novelty effects.

To sum up, facilitation for detection of a segment in a phonotactically illegal sequence

has been shown when listeners' weak expectations about an upcoming segment are defeated and the sequence itself is absolutely novel for the listeners (Experiments 1, 2, and 3 of the present study). Inhibition has been shown when listeners have strong expectations about an upcoming segment which are defeated, but when the sequence itself is not absolutely novel for the listeners (Experiment 4 of the present study and Gaskell & Marslen-Wilson, 1996; Gaskell & Marslen-Wilson, 1998; Kuijpers & Van Donselaar, in preparation; Otake et al., 1996). Otake et al., (1996) have also shown that detection of a segment that violates phonotactic constraints is inhibited when listeners have strong expectations about an upcoming segment and the sequence itself is a novel one for the listeners. How listeners process a segment that runs counter to weak expectations in a sequence that is not novel for the listeners has not been yet investigated. Following the explanation for the novel popout, inhibition would be expected, since popout requires a truly novel sequence for the listener. It is predicted that of all possible combinations of strong and weak expectations with sequences which never occur in the language (absolutely novel) and sequences which occur in other environments (not absolutely novel), only the combination of weak expectations together with a novel sequence causes facilitation in processing phonotactically illegal sequences.

The facilitation effect for violation of progressive assimilation has been observed so far only in a phoneme monitoring task. Listeners are specifically asked to focus their attention on the recognition of a single sound. During the processing of spontaneous speech in normal conversation, single sounds are usually not the focus of attention. Admittedly the link between phoneme monitoring and real language processing is only an indirect one, but in both cases listeners are presented with speech input which they have to process. There is, at least, evidence for the inhibitory effect of assimilation violation from other tasks. Koster (1987) and Gaskell and Marslen-Wilson (1996) observed inhibition for violation of assimilation in word recognition tasks. The inhibition effect is therefore not specific to phoneme monitoring, but whether the same is true for the facilitation effect is still a matter for further investigation.

So far the facilitation effect has been shown for violation of progressive assimilation. But interpretation of the effect depends on an assessment of its generality. If facilitation for phoneme recognition is due to a weak set restriction effect in combination with novel popout, then it might not be confined to assimilation violation. In fact, any other phonological restriction causing weak set restrictions and novel popout for the following segment might replicate the facilitation effect for violation of that restriction. In the same way, the inhibition effect has been observed for processes other than violation of assimilation. If anticipatory coarticulatory information fails to match the actual consonant which follows, processing has been shown to be adversely affected (Marslen-Wilson & Warren, 1994; Martin & Bunnell, 1981; McQueen, Norris, & Cutler, 1999; Whalen, 1984; Whalen, 1991). In these studies, performance on cross-spliced items that contain acoustic-phonetic mismatches was worse than on matching items. In McQueen et al. (1999) for instance, items like *sloop* 'pillowcase' were made by splicing *sloo* from *sloot* 'ditch' and adding the /p/ burst from *sloop*. Although formant transitions in the vowel signaled an upcoming /t/, the following segment was /p/. In other words, when hearing the vowel, the set of possible segments to follow was reduced to /t/, but /p/ occurred instead. Phonetic decision to the final stop was harder in items with mismatching information than in items without mismatching information. Further investi-

gations testing other phonological violations may show whether the facilitation effect can be replicated in the same way for other phonological restrictions. This would suggest that neither facilitation nor inhibition effects are assimilation-specific, but are rather general phoneme sequence effects. Further investigation is also necessary to determine the exact border between weak and strong set restriction effects.

The current study has shown evidence that the novel popout effect is operative not only in visual perception but also in speech perception. In most current models of speech perception, all sequences with zero transitional probability are treated equally, whether they are impossible in all environments or only in the one in question. The results reported here suggest that not all such sequences are processed in the same way. The finding of a novel popout effect for speech perception adds to our knowledge of mechanisms listeners use. It is hoped that future research will clarify the role of this effect.

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APPENDIX 1

Dutch target materials from Experiment 1 and Experiment 2

Targets with violation of the German progressive fricative assimilation.

[bɛxt], [blɪxt], [frɛxt], [frɪxt], [hɪxt], [kɛxt], [klɪxt], [krɛxt], [knɪxt], [nɛxt],
[pɛxt], [pɪxt], [prɛxt], [vɛxt]

Targets without violation of the German progressive fricative assimilation.

[baxt], [blaxt], [blɔxt], [brɔxt], [frɔxt], [haxt], [hɔxt], [kaxt], [knaxt], [nɔxt],
[plɔxt], [prɔxt], [raxt], [vɔxt].

APPENDIX 2

German target materials from Experiment 3

Monosyllabic targets

Targets with violation of the German progressive fricative assimilation.

[bɪxt], [dɛxt], [drɛxt], [kɛxt], [kɪxt], [mɛxt], [nɛxt], [pɪxt], [ʃɛxt], [ʃpɪxt], [tɛxt],
[tɪxt], [vɛxt], [zɛxt]

Targets without violation of the German progressive fricative assimilation.

[bɔxt], [dɔxt], [draxt], [kaxt], [kɔxt], [mɔxt], [nɔxt], [pɔxt], [ʃɔxt], [ʃpɔxt],
[tɔxt], [taxt], [vɔxt], [zɔxt]

Bisyllabic targets

Targets with violation of the German progressive fricative assimilation.

[blɪnxən], [bɛlxər], [dɛlxən], [fɛnxən], [krɪnxən], [lɪnxər], [mɛlxən], [nɛlxər],
[plɛnxən], [rɛlxən], [ʃlɪnxər], [ʃpɛnxər], [ʃpɪlxən], [tɪnxən]

Targets without violation of the German progressive fricative assimilation.

[blu:xən], [bo:xər], [do:xən], [fu:xən], [kru:xən], [lu:xər], [mauxən], [nauxər],
[pla:xən], [ra:xən], [ʃlo:xər], [ʃpauxər], [ʃpo:xən], [ta:xən]

APPENDIX 3

German target materials from Experiment 4.

Targets with violation of the German regressive place assimilation for nasals.

Alveolar-velar sequences:

[bɛnk], [bɪnk], [blɔnk], [fɛnk], [flɔnk], [frɔnk], [lɔnk], [pɛnk], [plɪnk], [pɔnk],
[fɪnk], [ʃlɔnk], [ʃrɔnk], [tɛnk]

Alveolar-bilabial sequences:

[bɛnp], [blɛnp], [dɔnp], [fɛnp], [flɔnp], [glɛnp], [lɛnp], [lɔnp], [ʃɛnp], [ʃlɔnp],
[tɛnp], [kɔnp], [tɔnp], [zɔnp]

Bilabial-velar sequences:

[bɛmk], [bɪmk], [blɔmk], [fɛmk], [flɔmk], [frɔmk], [lɔmk], [pɛmk], [plɪmk],
[pɔmk], [ʃmk], [ʃlɔmk], [ʃrɔmk], [tɛmk]

Velar-bilabial sequences:

[bɛŋp], [blɛŋp], [dɔŋp], [fɛŋp], [flɔŋp], [glɛŋp], [lɛŋp], [lɔŋp], [ʃɛŋp], [ʃlɔŋp],
[tɛŋp], [kɔŋp], [tɔŋp], [zɔŋp]

Targets without violation of the German regressive place assimilation for nasals.

Velar-velar sequences:

[bɛŋk], [bɪŋk], [blɔŋk], [fɛŋk], [flɔŋk], [frɔŋk], [lɔŋk], [pɛŋk], [plɪŋk], [pɔŋk],
[ʃŋk], [ʃlɔŋk], [ʃrɔŋk], [tɛŋk]

Bilabial-bilabial sequences:

[bɛmp], [blɛmp], [dɔmp], [fɛmp], [flɔmp], [glɛmp], [lɛmp], [lɔmp], [ʃɛmp],
[ʃlɔmp], [tɛmp], [kɔmp], [tɔmp], [zɔmp]
