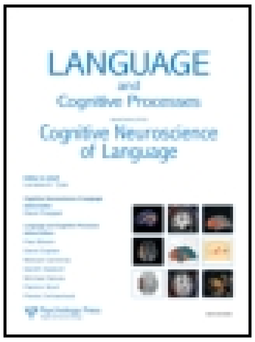

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Nasal and oral consonant similarity in speech errors: Exploring parallels with nasal consonant harmony

Rachel Walker
Department of Linguistics, University of Southern California, Los Angeles, CA, USA

Previous research has found that 'similar' sounds interact in phonological nasal consonant harmony, wherein certain consonants become nasals when the word contains a nasal (e.g., Kikongo: /-kun-idi/ → [-kun-ini] 'planted'). Across languages, stops and approximants are chiefly affected, especially voiced consonants and ones that match in place of articulation with the nasal. Three experiments investigated whether a parallel occurs in consonants showing greater likelihood to interact in speech errors with nasals. The experiments, which elicited errors using the SLIPS technique with English speakers, revealed the following asymmetries in consonants' participation in errors with nasals: (i) voiced stops (*b, d*) > voiceless stops (*p, t*), (ii) voiced stops with same place > voiced stops with different place, and (iii) approximants (*r, l*) > voiceless stops (*p, t*). These correlate with preferentially affected segments in nasal consonant harmony. The data support a uniform phonological similarity scaling for nasal-oral consonants across phonological harmony processes and speech errors. Further, they are consistent with theoretical proposals that consonant harmony has functional origins in facilitating language production.

Correspondence should be addressed to Rachel Walker, Department of Linguistics, 3601 Watt Way, GFS 301, University of Southern California, Los Angeles, CA 90089–1693, USA; E-mail: rwalker@usc.edu

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INTRODUCTION

The similarity of speech sounds has been observed to influence their potential to interact in certain phonological processes. Phonological consonant harmonies are a case in point. In such patterns, certain consonants in a word are obliged to be identical for some property. For example, in nasal consonant harmony, certain oral consonants are produced as nasals when a nasal occurs elsewhere in the word. Kikongo offers exemplification: the suffix -*idi*, e.g., [-suk-idi] 'washed', is realised as –*ini* when preceded by a nasal in the stem, e.g., [-kun-ini] 'planted' (Rose & Walker, 2004). The harmony is long-distance in that the matching consonants may be separated by (at least) a vowel, which remains oral. Several studies have observed that nasal consonant harmony affects segments that are highly similar to nasals in phonological and phonetic terms, primarily stops (e.g., voiced: *b, d,* voiceless: *p, t*) and approximants (liquids, e.g., *l* and glides, e.g., *j, w*) (Hansson, 2001; Rose & Walker, 2004; Walker, 2000a). Especially prone to participation are consonants that are voiced or match in place of articulation with the nasal. Moreover, it has been demonstrated that *all* kinds of consonant harmony favour interactions between consonants with high phonological similarity (Hansson, 2001; Rose & Walker, 2004; for related observations, see Frisch, Pierrehumbert, & Broe, 2004; MacEachern, 1999; van de Weijer, 1994). This includes harmony for laryngeal features, tongue tip and blade features in coronal consonants, and others.

Taking nasal consonant harmony as a point of departure, this study explores whether a parallel is found in the consonants that tend to interact with nasals in phonological speech errors. While it is widely agreed that 'similar' consonants are more prone to participate in speech errors, this study investigates whether the categories of phonologically similar consonants identified by nasal consonant harmony are the same as those witnessed in patterns of error production. This research is connected to a proposal in phonological theory. Consonant harmony is suggested to have functional roots in language production, specifically, in speech planning and articulatory implementation (Hansson, 2001; Rose & Walker, 2004; Walker, 2000a,b).[1]

The existence of commonalities between consonant harmony and speech errors was noted by Dressler in his study of aphasic errors, which he interprets as 'exaggerations of normal speech errors' (Dressler, 1979, p. 23). He noticed that, like consonant harmony, aphasic errors produce distant assimilations among consonants such as *n*/*l* (e.g., *Nähnadel*→[l̠eːnaːdl̠] 'sewing needle') and *l*/*r* (e.g., *Lautlehre*→[r̠aotleːr̠ə] 'phonetics'). However,

[1] See Frisch (1996, 2004) for other work supporting the claim that phonological encoding shapes grammar. Further, Frisch et al. (2004) discuss how speech processing factors influence the lexicon and phonological processes.

lacking the benefit of later surveys that demonstrated the breadth of occurrence of phonological consonant harmony, Dressler stated that 'natural languages show almost no instances of consonant harmony' (Dressler, 1979, p. 23). Dressler (1978) observed that speech errors might be the source of sporadic cases of assimilation at a distance among segments or clusters in language change, as in Italian *c̲oc̲odrillo* 'crocodile' from Ancient Greek *k̲rok̲ódilos*. Yet he regards this as occurring 'only for very few words of a language' (Dressler, 1978, p. 148). Subsequent research in phonology has revealed that consonant harmony is well attested in natural language, and it has emphasized parallels between consonant harmony and speech errors (Hansson, 2001; Rose & Walker, 2004; Walker, 2000a, 2000b). Among these shared properties, two are particularly relevant: (i) the potential for action-at-a-distance, i.e., that both consonant harmony and speech errors may take place across intervening, unaffected segments, such as vowels and certain dissimilar consonants, and (ii) the role of similarity, i.e., that phonologically similar consonants are more likely to interact in consonant harmony and to participate in errors. This study focuses on the latter point for nasal consonant harmony.

In this paper I first provide an overview of attested nasal consonant harmony patterns and identify the phonological similarity ranking for nasal-oral consonant pairs with which they are consistent. I then review the relevant background which gives shape to a series of speech error experiments with speakers of English testing the relative similarity of nasal stops and classes of oral consonants in language production. English does not have nasal consonant harmony. This study examines a language that lacks such harmony in order to test the phonological similarity of nasal-oral consonants in error patterns without interference from the language's grammar. The experiments and their results are presented in turn followed by a general discussion.[2]

Nasal consonant harmony and linguistic theory

Relevant patterns of nasal consonant harmony are found in the Bantu languages, Kikongo and (Lu)Ganda. Nasal consonant harmony in Kikongo causes voiced stops and /l/ to become a nasal stop when a nasal stop occurs prior in the word stem, as in (1a–b) (Ao, 1991; Bentley, 1887; Dereau, 1955; Odden, 1994). Thus, in [-nik-in̲i], the active perfect suffix *–idi* becomes *–ini* through harmony with [n]. Intervening vowels and voiceless /k/ remain oral. Likewise, the approximant /l/ in the applicative suffix *-il* becomes a nasal in

[2] In other research, it would be valuable to investigate speech errors in a language with nasal consonant harmony to examine how they differ, if at all, from error patterns of languages without such harmony.

[-dumuk-is-in̲-a] by harmony with [m]. In this case, oral vowels and voiceless consonants /k/ and /s/ occur between the harmonising consonants.

(1)	*Oral consonant in suffix*		*Nasal consonant in suffix*	
a.	-suk-iḏi	'washed'	-nik-in̲i	'ground'
	-bud-iḏi	'hit'	-sim-in̲i	'prohibited'
b.	-sakid-iḻ-a	'congratulate for'	-nat-in̲-a	'carry for'
	-toot-iḻ-a	'harvest for'	-dumuk-is-in̲-a	'cause to jump for'

The examples in (1) show that nasal consonant harmony can cause suffixes to present a variant with a nasal. It also enforces static patterns in the lexicon (Piggott, 1996; Rose & Walker, 2004). There are no roots in Kikongo containing a voiced stop or approximant preceded by a nasal at any distance (/l/ is Kikongo's only approximant; Ao, 1991). Two nasals are permissible, however, as is a nasal followed by a voiceless stop, as in the root [-nat-] in (1b). In short, voiced stops and /l/ harmonise with a nasal that occurs prior in the stem in Kikongo. The nasal and harmonising consonant can match in place of articulation or differ. Vowels and voiceless consonants may occur between harmonising consonants but do not themselves become nasal(ised).[3]

Nasal consonant harmony in Ganda differs in the set of affected consonants. Harmony in Ganda restricts combinations of consonants in roots (Hansson, 2001; Katamba & Hyman, 1991; Rose & Walker, 2004). Three consonant series are relevant: nasals, voiced stops, and voiceless stops. Several voiced stops show approximant variants: [b/β], [d/l], [ɟ/j]. In roots, nasals and voiced stops/approximants with the same place of articulation must match in nasality. As a result, nasal harmony prevents roots that contain a nasal and voiced stop (or approximant variant) with the same place (with rare exceptions). This holds whether the nasal or voiced stop comes first. Thus, for example, bilabial [b/β] and [m] do not occur together in a root nor do coronal [d/l] and [n]. However, identical nasals or voiced stops/approximants may co-occur, as shown in (2a). Nasal harmony does not occur if a nasal and voiced consonant have different places of articulation, as seen in (2b).[4] Bilabial [b] and coronal [n] are thereby permitted to co-occur in a root, as are bilabial [m] and coronal [l]. Further, harmony occurs between a nasal and a voiceless stop with the same place of articulation, provided that the nasal precedes the voiceless stop, i.e., a hypothetical root like *nat* is

[3] On the patterning of nasal-oral stop clusters in Kikongo's harmony, see Rose & Walker (2004).

[4] This description of Ganda's nasal consonant harmony focuses on restrictions involving nasals and singleton oral consonants. Examples are from the Comparative Bantu On-Line Dictionary (http://cbold.ddl.ish-lyon.cnrs.fr). Combinations of nasals and voiced stops with different place are subject to some specific limitations (Katamba & Hyman, 1991). What is essential is that restrictions on nasals and place-matched voiced stops are broader in scope.

systematically prevented. However, harmony does not occur if a voiceless stop precedes a nasal with same place, as in [-táná] 'grow septic, fester'.

(2) *Ganda consonant combinations in roots*

a.	-mémèká	'accuse, denounce'	-nónà	'fetch, go for'
	-bábùlá	'smoke over fire to make supple'	-gùgá	'curry favour with'
b.	-bónèká	'become visible'	-màlà	'finish'

In sum, the relevant pattern found in Ganda is that certain consonants occurring together in a root must agree in nasality if they have the same place of articulation. Also, voiceless stops are affected in a subset of the contexts in which their voiced counterparts are.

The following statements express certain cross-linguistic implications for consonants that participate with nasals in harmony, as exemplified by Ganda and Kikongo. These are consistent with the additional cases surveyed in Hansson (2001) and Rose & Walker (2004).

(3) *Some implications for participant sounds in nasal consonant harmony*

a. Participation of voiceless stops with same place implies participation of voiced stops with same place.
b. Participation of voiced stops with different place implies participation of voiced stops with same place.
c. Participation of voiceless stops with same place implies participation of approximants with same place.

Furthermore, while both liquids and glides participate in Ganda's harmony, in several patterns of nasal consonant harmony, [l] is the only approximant reported to participate (Hansson, 2001; Rose & Walker, 2004). This will be relevant for the materials used in Experiment 3.

On the basis of the implications in (3) and the observation that nasals are prone to interact with similar sounds in consonant harmony, the similarity scales in (4) are suggested, which contribute to the experiments' design. These cross two sub-scales based on sounds' similarity with nasals: (i) voiced stop, approximant > voiceless stop, and (ii) same place > different place.

(4) *Nasal phonological similarity scaling*

a. A nasal is more similar to a voiced stop with the same place of articulation than to a voiced stop with different place or a voiceless stop with the same place.
b. A nasal is more similar to an approximant with the same place of articulation than to an approximant with different place or a voiceless stop with the same place.

The nasal similarity scaling finds extrinsic support from phonetics. Nasals and voiced stops each present voicing, and nasals and oral consonants with the same place of articulation match in constriction location. Further, nasals and oral stops with the same place show similar effects on vowel formant transitions. Nasals and approximant consonants share voicing, and their continuous non-turbulent airflow causes each to present weak formant structures.

This study has a theoretical context. A correlation has been suggested between assimilations involving highly similar consonants and the potential for interaction between non-adjacent consonants. For instance, in nasal consonant harmony, phonologically similar consonants interact, and they may harmonise at a distance. In contrast, nasal consonant-vowel harmony does not show these properties. In such harmony, nasalisation is extended from a nasal segment over a (near-)continuous sequence of segments that includes vowels and might also include other consonants (Walker, 2000c). For example, in Malay, nasalisation carries from a nasal stop through a following sequence of vowel and glides, as in [mə̃nãw̃ãn] 'to capture (ACTIVE)' (Onn, 1980). However, this procedure is not applicable to nasal consonant harmony, where intervening oral vowels and voiceless consonants indicate a lack of continuous nasalisation carrying between harmonising segments. Furthermore, stops and liquids do not undergo nasal harmony in Malay, despite their similarity to nasals, e.g., [mə̃r̠atappi] 'to cause to cry,' [pəmãnd̠aŋãn] 'scenery'.[5]

For consonant harmony, it has been argued that a different mechanism is at work. The occurrence of relatively high phonological similarity between consonants is suggested to stimulate a formal phonological relation to be constructed between them, causing the consonants to become 'coindexed' with

[5] Some phonological processes cause nasal assimilation between stops in clusters, e.g., /nd/ becoming [nn] or, for processes operating in the opposite direction, /gm/ becoming [ŋm]. Phenomena of this kind are not categorized by phonologists as a type of 'consonant harmony' because they do not involve a long-distance interaction, i.e., they neither operate between non-adjacent segments nor do they affect sequences of more than two segments. Nevertheless, one might ask whether phonological similarity plays a role in identifying which segments are most likely to participate in such processes, for example, whether clusters like [dn] or [nd] would be more likely than [tn] or [nt] to become [nn]. To begin, the issue is an empirical one. I am not aware of any cross-linguistic study that has explored whether voiced stops are more likely than voiceless stops to become nasals in clusters with a nasal. If this were established to be so, further investigation would be required in the context of individual linguistic systems to determine whether phonological similarity between a nasal and voiced stop is what caused their increased potential for interaction. Unlike assimilations involving consonants separated by a vowel or more, consonants in a cluster are adjacent, which introduces other factors that might be a source of nasalization in an adjacent stop. These include conditions on syllable contact, possible syllable onsets and codas (singletons and clusters), perceptibility of segmental contrasts within clusters, and so on. This is a topic that merits future research.

one another (Hansson, 2001; Rose & Walker, 2004; Walker, 2000a, 2000b). The relation established between similar segments mediates nasal consonant harmony. Constraints that require identical phonological feature specifications in related segments enforce matching for individual properties, such as nasality. Thus, for example, Kikongo's /n_{α}ik – id_{α}i/ becomes [n_{α}ik – in_{α}i], because the co-indexed consonants must match for the dimension of nasality.

The relation's functional origins are hypothesised to lie in speech planning (and possibly speech execution, as addressed later). Psycholinguistic studies in association with spreading-activation models have found evidence that speakers and listeners form connections in an utterance between similar speech sounds (e.g., Dell, 1984, 1986; Dell & Reich, 1980; MacKay, 1970a, 1987; McClelland & Rumelhart, 1981; Stemberger, 1982, 1985a, 1985b). In addition, in order for sounds to interact in phonological encoding phenomena, such as speech errors, they need not be contiguous, for example, they often belong to onsets of separate syllables (Berg, 1998; MacKay, 1970a; Shattuck-Hufnagel, 1983, 1985, 1987). Errors occur most often across words, at least in English. This is partly because errors are more likely to occur among segments in stressed syllables (Shattuck-Hufnagel, 1985, 1986) and many words have only one stressed syllable (errors are also more frequent in word-onsets). An assumption underlying the functional grounding is that the relative proportion of errors for a consonant contrast (e.g., *m/b*) in between-word errors will correlate to within-word processing, even if there are fewer within-word errors.

Phonological similarity in speech errors

It has been well-established that the likelihood of two phonemes participating in a speech error increases with phonological similarity (Berg, 1998, 2004; Frisch, 1996; Fromkin, 1971; Garrett, 1975; Kupin, 1982; Levitt & Healy, 1985; MacKay, 1970a; Meyer, 1992; Nooteboom, 1967; Shattuck-Hufnagel & Klatt, 1979; Stemberger, 1982, 1985b, 1991b; Vousden, Brown, & Harley, 2000). Hence, both consonant harmony and speech errors show increased potential for interaction between similar sounds. Focusing on nasal harmony, this raises the issue of whether a parallel exists between the consonants affected in nasal consonant harmony and those more likely to participate with nasals in speech errors.

Previous research bears on this issue. An English speech error study by Stemberger (1991b) using the SLIPS technique found more errors between nasals and voiced obstruents than nasals and voiceless obstruents in both nasal-stop pairs and nasal-fricative pairs. This indicates a similarity effect of shared voicing in nasal-obstruent contrasts. The sub-finding of more errors with nasal-voiced stop pairs than nasal-voiceless stop pairs correlates with the similarity effect for voicing seen in nasal consonant harmony affecting stops.

In another SLIPS experiment, Stemberger (1991b) found that labial-labial stop-fricative pairs (*b*/*f*) showed more errors than ones that differ in place (*d*/*f*, *b*/*s*). Labial-labial stop-fricative pairs also showed more errors than alveolar-alveolar ones (*d*/*s*). Shared labial place in stop-fricative contrasts thus increases the error rate. Further, Stemberger's (1991b) analysis of a speech error corpus found that similarity effects in consonants with shared place show sensitivity to manner. Labial-labial pairs were more likely to participate in errors than alveolar-alveolar pairs in contrasts where at least one consonant is a fricative. However, error rate asymmetries for paired labials vs. paired alveolars were not found for oral stop-nasal contrasts or voiced-voiceless stop contrasts. Stemberger speculates that differences in place only produce a significant effect in fricative pairings because errors involving them are less frequent, and factors influencing error rates are greatest for less frequent error types. In patterns of nasal consonant harmony that affect only stops with the same place, harmony applies to both labial-labial and coronal-coronal pairs. This falls in line with the lack of difference across these places that Stemberger found.

Relevant to observed similarity effects is the objective computation of phonological similarity. Proposals have been made to compute similarity on the basis of phonological features and/or phonetic knowledge in the context of a language's phonological system (e.g., Frisch et al., 2004; Kawahara, 2005; Steriade, in press; papers collected in Frigeni, Hirayama, & Mackenzie, 2005). Research in the context of speech error research includes van den Broecke and Goldstein (1980), Frisch (1996, 2004), Levitt and Healy (1985), Rose and King (in press), and Vousden et al. (2000).[6] The similarity metric proposed by Frisch et al. (2004) has been examined in the context of phonological consonant patterns and speech errors. A key aspect of this metric is that some phonological features may potentially contribute more to similarity than others.

The method proposed by Frisch et al. (2004) computes similarity based on phonological feature classes. Phonological similarity is obtained by calculating the shared feature classes of two segments in a given language and dividing it by the number of shared feature classes plus non-shared feature classes. The feature classes metric is sensitive to segmental contrast. Frisch et al. (2004, p. 197) characterise feature classes as 'natural classes'. As they point out, features that are non-contrastive within a language's segment

[6] See Stemberger (1991b) for a representational approach to consonant similarity using feature underspecification. Representational approaches have also been applied to certain patterns of nasal harmony where it is proposed that nasals and voiced stops interact in nasal harmony to the exclusion of voiceless stops because they share certain structure in their feature geometry (Piggott, 1992; Rice, 1993). However, the patterns that work addresses are sub-cases of nasal consonant-vowel harmony rather than the nasal consonant harmony under focus here.

inventory do not define a unique natural class, and they will thus not augment similarity. Further, features that are contrastive for only a subset of the segments in an inventory will contribute to defining natural classes only in categories for which they are contrastive. For example, in a language where all sonorant sounds are voiced, but voicing is contrastive in obstruents, the feature [+voice] will not define a natural class in [+sonorant] sounds but it will define distinct classes in combination with classes involving [–sonorant]. As a result, partially contrastive features will contribute to similarity, but to a lesser degree than fully contrastive ones. Under this method, the similarity rating for a pair of sounds varies somewhat according to a language's segment inventory. Pierrehumbert (1993) and Frisch (1996) make a similar point, namely, that the comparison set impacts perception of similarity.

Frisch et al. (2004) argue that the feature classes model is largely effective in calculating similarity for segments in dissimilatory phonological phenomena. Rose and Walker (2004) find it generally suitable for identifying the sound groups that are favoured participants in consonant harmony,[7] but they observe that the similarity computation could be further refined by adjusting the weight that certain features carry (see also Frisch et al., 2004). The feature classes metric has also been successfully applied to speech error data by Frisch (1996). While it is not the intention of the present research to evaluate this similarity metric, it is relevant for a part of this study investigating the relative contribution of different features to consonant similarity.

The feature classes model computes similarity as symmetrical, e.g., [m] is as similar to [b] as [b] is to [m]. Frisch (1996) found sufficient symmetry in the error data he examined for a symmetric model to make significant generalisations. Nevertheless, Frisch noted a possible revised calculation that could model asymmetries in speech errors and phonological phenomena. Stemberger (1991a, 1991b) identified asymmetries in speech error rates where one consonant in a pair is more likely to substitute for the other. One finding is that stops are more likely to be replaced by nasals than the reverse in a SLIPS experiment. This finds a parallel in nasal consonant harmony, where nasals are far more likely to cause an oral consonant to become nasal than the reverse (Hansson, 2001; Rose & Walker, 2004). Also, in consonant harmony in child phonology, more children replace oral stops with nasals than the reverse (Stoel-Gammon & Stemberger, 1994). Stemberger (1991a) proposed that the asymmetry is caused by underspecification of [–nasal], i.e., the absence of this specification in oral sounds. Later work by Frisch (1996) used a tongue twister paradigm to test for asymmetries in error rates for

[7] Hansson (2001) identifies a problem that arises under circumstances of an inventory in which a consonant is asymmetrically unpaired in its series for a value of the harmonizing feature. See Frisch et al. (2004) for discussion.

various contrasts identified by Stemberger (1991a) as asymmetrical. Frisch found evidence for asymmetries in only some of the contrasts. He did not find a significant asymmetry for the nasal-stop contrast. Frisch observed that the difference between his findings and Stemberger's suggests that some asymmetries Stemberger found are dependent on the method of error induction and the particular stimuli used.

Overview of experiments

By requiring similar sounds to match for some property, consonant harmony is proposed to have the effect of eliminating certain combinations with a relatively high chance of causing interference in language production. If the present experiments find that the same similarity is operative in speech errors as in nasal consonant harmony, the results would be consistent with the proposal that phonological consonant harmony has roots in facilitating ease of speech production. Growing out of the cross-linguistic patterns of nasal consonant harmony and previous research on similarity in speech errors, three experiments were conducted to test the hypotheses in (5).

(5) *Hypotheses tested by experiments*

a. Experiment 1: Voicing
H1: There will be more errors involving nasals and voiced stops than nasals and voiceless stops.

b. Experiment 2: Place
H2: There will be more errors involving nasals and voiced stops with the same place of articulation than nasals and voiced stops with different place.

c. Experiment 3: Manner: property weighting
H3: There will be more errors involving nasals and approximants with (partially) same place than involving nasals and voiceless stops with the same place.

The language investigated is English. Figure 1 gives the stops and liquids of English and their plain (non-geminate) counterparts in Kikongo and Ganda, the languages for which nasal consonant harmony was illustrated above. The experiments examine bilabial and coronal consonants only, because the velar nasal does not occur word-initially in English. The relevant stops, boxed in Figure 1, are comparable across the three languages (though Ganda shows approximant variants for its voiced stops).[8] In regard to liquids, each language presents [l] (in Ganda, *l/d* are not in contrast), and

[8] The phoneme /l/ in Kikongo is realized as [d] when followed by [i] or preceded by a nasal. It is pronounced as [l] elsewhere. Apart from this alternation, /d/ exists as a separate phoneme in the language.

English

p	t	k
b	d	g
m	n	ŋ
	l,r$^{(w)}$	

Kikongo

p	t	k
b	d	g
m	n	
	l	

Ganda

p	t	c	k
b/β	d/l	ɟ/j	g
m	n	ɲ	ŋ
	(l)		

Figure 1. Stop and liquid inventories.

English also has /r/. English [r$^{(w)}$] is listed in the column of coronal consonants, although as discussed below, many speakers also produce it with labialisation in syllable onsets. English [l] and [r] also involve lesser constrictions at the back: tongue dorsum backing in [l] and tongue root retraction in [r] (Gick, 1999). These lesser constrictions were not expected to substantially detract from these segments' similarities to the nasals under comparison.

Experiment 1 partially replicates Stemberger's (1991b) experiment which investigated whether more errors occur for nasals and voiced obstruents than nasals and voiceless obstruents. Experiment 2 examines the effect of shared place in nasal-voiced stop contrasts. While shared place has been examined for another contrast, the nasal-voiced stop contrast has not been examined before using the SLIPS technique. Whereas Experiments 1 and 2 and most previous work focus on similarity effects for different values of a given feature, Experiment 3 compares the contribution of different shared features to consonants' similarity, an issue relevant to comparing similarity in speech errors and nasal consonant harmony. Apart from nasality, the shared/different properties of consonants examined in Experiment 3 are as follows. Nasals and approximants are voiced and sonorant, but they differ in stricture. Nasals are produced with complete oral occlusion, while approximants present oral airflow. Also, [l] differs from nasals in being lateral. On the other hand, nasals and voiceless stops match in stricture, both having full stoppage in the oral cavity. However, nasals are sonorants, while voiceless stops are obstruents, and they differ in voicing.

In Experiments 1, 2 and 3, sub-questions examined whether place of articulation of the nasal consonant affects the error rate and whether the order of nasal-oral consonants affects the error rate. Data analysis also explored possible interactions with other factors. The findings generally did not prove to be sufficiently consistent and/or of primary theoretical interest to warrant reporting here (but see discussion of place of articulation in Experiment 2 below).

EXPERIMENT 1: VOICING

Experiment 1 investigated the hypothesis that there will be more errors involving nasals and voiced stops than nasals and voiceless stops.

Error induction technique

All experiments employed the SLIPS technique, which uses phonological priming to generate initial consonant ordering errors in word pairs (Baars & Motley, 1974; Baars, Motley, & MacKay, 1975; Motley & Baars, 1975; applications include Dell, 1984, 1990; Stemberger, 1991a, 1991b; Stemberger & Treiman, 1986). Participants are shown monosyllabic word pairs, one pair at a time, on a video screen for silent reading. Some word pairs are followed by a cue for participants to speak aloud the immediately preceding word pair. Cued pairs with phonological priming are referred to as critical pairs. Immediately preceding a critical pair are three priming pairs designed to promote a speech error involving the initial consonants. Priming pairs are not cued. In the priming structure used here, the words in the first priming pair rhymed with the critical pair words but had different initial consonants. In the second and third priming pairs, the initial consonant-vowel sequences (but not the final consonant) matched the words in the critical pair, but in the opposite order. Table 1 shows two sample priming structures, one in which the vowels in the critical pair are the same and one in which they are different. Taking, for example, the priming structure for the leftmost pair, the initial consonants in the two immediately preceding priming pairs are sequenced [m]-[p], but those in the critical pair are reversed, [p]-[m]. The priming structure increases the likelihood that subjects will slip in production of the initial consonants in the critical pair, *pat mass*, producing, for example, *mat pass* (exchange), *mat mass* (anticipation) or *pat pass* (perseveration). The first priming pair, with rhyming, is intended to bias for a correct production of the vowel-consonant portion of the critical words.

Method

Subjects. Subjects were 35 undergraduates at the University of Southern California who were native speakers of English. There were 22 subjects enrolled in psychology courses, who received course credit for participation, and 13 others, who received monetary compensation.

Materials. The stimuli consisted of pairs of monosyllabic real English words. All words were of the form consonant-vowel-consonant. The word list contained 160 critical pairs and 480 priming pairs, with priming structure designed as in Table 1. All critical pairs changed into real words of English

TABLE 1
Sample priming structures, Experiment 1

Priming pair 1, rhymes with critical pair	*cat sass*	*sum peck*
Priming pair 2, initial CVs match critical pair, but in opposite order	*mad pack*	*den null*
Priming pair 3, initial CVs match critical pair, but in opposite order	*match pan*	*debt nut*
Critical pair	*pat mass*	*numb deck*
Cue to recall critical pair	*?????*	*?????*

under an exchange, anticipation or perservation error with the initial consonants. The list of critical pairs used in Experiment 1 is included in Appendix A. The composition of the critical pairs was controlled for the five factors listed in (6), fully crossed.

(6) *Experiment 1: Controlled factors in critical pairs*

i. Voicing: initial nasal and voiced stop word pairs (*m*/*b*, *n*/*d*) vs. initial nasal and voiceless stop (*m*/*p*, *n*/*t*).
ii. Place: bilabial [m, b, p] vs. alveolar [n, d, t] initial consonants within a word pair.
iii. Order: nasal-initial word first vs. oral stop-initial word first.
iv Vowel: same vs. different vowels within words in a pair.
v. Earliness: word pair cued in first half of the experiment or the second half.

Factor (i) is related to the hypothesis under investigation. The remaining factors were controlled to balance for the given levels.[9] Factor (iv) controls for the 'repeated phoneme effect', in which a pair of sounds that are both preceded or both followed by a repeated phoneme are more likely to participate in a speech error (Dell, 1984; MacKay, 1970a; Nooteboom, 1967; Shattuck-Hufnagel, 1985; Wickelgren, 1969). For example, the repeated /i/ in the initial syllables of the words *weekly reading* could encourage a slip such as *reekly weeding*. Factor (v) was controlled in case there was a tendency for subjects to produce more errors early or late in the experiment. Fewer errors late in the experiment could arise due to subjects' exposure to the task or more errors late in the experiment could occur because of fatigue. If subjects' error rates declined or increased, the control for factor (v) prevents an effect on the issue under study.[10]

[9] Stemberger (1991a) found that whether the nasal is in the first or second word does not matter in SLIPS experiments in errors involving nasals and stops (order did not matter for any contrast that he examined). The order factor was controlled because it was relevant for a subquestion of the experiments that is not reported on here.

[10] Data analysis was performed on the factor of earliness but the results are not reported here, as they are not relevant for the theoretical issue under investigation.

The word list was split into two halves equally balanced for factors (i)–(iv) in (6). In addition to critical pairs and primes, the list included 500 filler pairs, 200 of which were cued for subjects to say aloud. Cued filler pairs were preceded by between zero and three uncued filler pairs, which were not organised into a phonological priming structure. The order of critical pairs (each together with their preceding primes) within the list was randomised; however, sequences of cued pairs containing the same word were prevented. Filler pairs were interspersed to obscure the phonological priming structure. Both the number of cued filler pairs intervening between critical pairs (and their primes) and the number of uncued fillers that preceded each cued filler were randomised. Adjacent pairs that contained the same word were prevented. Word pairs that formed special phrases, e.g., 'love sick', were excluded, as were pairs with rhyming words.

Working within the balanced factors in (6), critical words were selected so as to narrow the mean frequency within a place of articulation. Two databases were used as a basis to compute mean frequency: word frequencies were drawn from Carroll, Davies, & Richman (1971) and Zeno (1995). Mean word frequencies were as follows (*SD* in parentheses). In pairs for the *m*/*b* contrast, 215.2 (240.1) for words with initial [b] and 219.6 (255.8) for initial [m]. In pairs for the *m*/*p* contrast, 194.1 (181.7) for words with initial [p] and 361.2 (476.8) for initial [m]. For the *n*/*d* contrast, 259.3 (438.7) for words with initial [d] and 634.8 (1272.2) for initial [n]. In pairs for the *n*/*t* contrast, 220.4 (271.1) for words with initial [t] and 594.6 (928.6) for initial [n]. Within critical pairs, words were more closely matched for lexical frequency (in bilabial pairs mean $SD = 69\%$ of standard deviation for the entire set of bilabial-initial words used in the experiment, and in alveolar pairs mean $SD = 54\%$ of that for the entire set of alveolar-initial words).[11] Frequencies were not balanced across contrasts with [m] vs. [n]. Comparison of error rates across those contrasts could be complicated by frequency but are not under focus here.

Each pair of words used in a critical pair occurred twice in the list, once with the nasal-initial word first and once with the reverse order (e.g., *mass pat*, *pat mass*). In order to meet the restrictions imposed by the factors in (6), some words were used in two separate pairs so that they appeared four times in critical pairs (e.g., *mail pad, pad mail, mail pile, pile mail*). To control for within-list frequency, each word appeared in the list exactly six

[11] More errors occur in production of low frequency words (e.g., as a target word in a critical pair) than in high frequency ones (Dell, 1990; Stemberger & MacWhinney, 1986). This motivates narrowing lexical frequency within groups of critical pair words and within critical pairs. In contrast, errors that form real words do not seem to show outcome-based effects of lexical frequency. Dell (1990:331) finds that 'there is little tendency for [phonological speech] errors to create high-frequency over low-frequency outcomes' (see also Dell & Reich, 1981; Garrett, 1976).

times. This was true not only of words in critical pairs, but also of all words in the list. Each half of the list was balanced for factors in (6). However, as words in critical pairs appeared more than once, the randomised word list was further examined to ensure that if repetition priming were to occur, it would not asymmetrically bias the conditions under study. Taking one half of the list first, each critical word's number of occurrences was tallied at the quarter point of the list and the half point. There were overall comparable exposures at these intervals for words in the critical pair categories under comparison. Means were as follows (*SD* in parentheses): words in pairs with initial *m*/*b* at quarter point 1.36 (0.76) and at half 3.12 (0.33) vs. initial *m*/*p* at quarter 1.33 (1.01) and at half 3.13 (.54); words in pairs with initial *n*/*d* at quarter point 1.58 (1.06) and at half 3.25 (0.61), vs. initial *n*/*t* at quarter 1.96 (1.0) and at half 3.15 (0.54). Further, for each critical pair in the second half of the list, the number of previous occurrences of each pair's words were examined. Again, the conditions under comparison appeared balanced. The mean for *m*/*b* critical pairs was 4.08 (0.8) and for *m*/*p* 4.08 (0.94). For *n*/*d* pairs the mean was 4.13 (0.82) and for *n*/*t* 4.08 (0.8). Therefore, the word list's structure was such that repetition priming would be unlikely to unevenly skew error rates for levels of the factor under study.[12]

Procedure. Subjects were seated in a sound-insulated room in front of a video screen controlled by a computer. Each word pair was presented on the centre of the screen for 900 ms followed by 100 ms of blank screen. Word pairs were presented in lower case in Charcoal font. Subjects were instructed to read pairs silently and prepare to say them aloud as quickly as possible if cued to do so. In cued trials, after the 100 ms of blank screen, a string of question marks appeared for 600 ms followed by 500 ms of the deadline message 'finish speaking now' and then 350 ms of blank screen. In total, each trial for a non-cued pair was 1 s and for a cued pair was 2.45 s. All subjects were exposed to the same word list, but alternate subjects were given one half of the word list first versus the other. Subjects were trained on 12 word pairs, four of which were cued. None of the words used in the training phase were included in the actual experiment. The entire experiment took 35–40 minutes, including an optional five minute break at the halfway point. Responses were audio-recorded for later analysis and were coded during the course of the experiment by an investigator using a button box.

[12] While repetition priming is unlikely to lead to the differences in error rates found in the experiment, it is possible that the magnitude of differences in error rates could be smaller for the second repetition of critical pairs, making the detection of differences more difficult.

Results and discussion

Subjects' productions of each critical pair were coded. A first coding pass was performed during the experiment by an investigator using a button box. After the experiment, coding was verified by an investigator listening to the audio recording of responses. Any cases of disagreement were resolved by two investigators listening to the pairs again. Codes assigned to subjects' productions of critical pairs were as follows: *correct production*, assigned for no audible error, *initial consonant error*, assigned where the initial consonants participated in an exchange error or one initial consonant apparently replaced the other, and *other*, assigned to errors that did not fall in the initial consonant error category. The investigator listening to the audio tape transcribed and classified initial consonant errors according to the categories listed in Table 2.

False start errors (sometimes called 'incomplete anticipations') were coded separately from exchanges and anticipations, because they were ambiguous between these error types. The stimuli construction in this experiment primed for exchanges, resulting in more errors of this kind (Stemberger, 1992a). Exchange errors were subclassified into *consonant exchanges*, where initial consonants alone were switched, and *word exchanges*, where the words were apparently reversed. In some cases the level of linguistic organisation at which the errors took place is ambiguous. For example, the anticipation error in Table 2 could have taken place at the segmental level, substituting [m] for [b] (e.g., Fromkin, 1971), or at the subsegmental level, where the feature [nasal] (or lowered velum gesture) intrudes on the initial consonant in the first word (e.g., Browman & Goldstein, 1990). Similarly the example word exchange error could arise from word reversal, exchanging all phonemes, or from simultaneous reversal of the initial and final consonants. Nevertheless, since the initial consonants are involved in all of these errors, their degree of similarity could contribute to the error rate, and they were thus included in the error tally. Productions categorised as *other* were produced incorrectly but not involving the initial consonants. Examples include errors limited to the vowels or coda consonants, e.g., *noon duke* → *noon duck*, *beak meat* → *beak meek*. Also included here were apparent memory errors, where subjects said nothing when cued or remembered only the first word of the pair. A third error type coded as *other* were cases where subjects said aloud a priming pair when cued instead of the critical pair. Productions categorised as *other* were not included in error counts for statistical analysis.

There were 159 initial consonant errors, yielding a mean error rate of 2.83% (the proportion of critical pair trials in which an error occurred). An alpha

TABLE 2
Speech error categorisation: Initial consonant errors

Type	*Examples*
Exchange	
Consonant	near tail → tear nail
Word	mutt puff → puff mutt
Anticipation	bone mode → moan mode
Perseveration	numb deck → numb neck
False start	mile pad → pi—mile pad
	meat beak → beat —

level of .05 was used for all statistical tests. There were 95 errors in critical pairs containing an initial nasal and initial voiced stop (either order) vs. only 64 errors in critical pairs containing an initial nasal and initial voiceless stop (either order). This difference was found to be significant, using a Mann–Whitney U test; 23 out of 35 subjects made more errors involving nasals and voiced stops (only 4 subjects showed the opposite pattern, 8 subjects produced the same number of errors in each condition), $U(1) = 441.5, p < .05$. Similarly, there were typically more errors for critical pair items with nasals and voiced stops than for items with nasals and voiceless stops, $U(1) = 595.5, p < .05$. In Table 3, the data are broken down by voicing and place of articulation. Both bilabial and alveolar consonants showed similar trends. Notice that consonant exchange errors account for about half of the total errors (52%). This is consistent with Stemberger's (1991a) observation that the SLIPS technique generates a high proportion of exchange errors for the oral stop-nasal contrast, usually about 50%. Among anticipations and perseverations, a nasal substituted for an oral stop in 16 errors and the reverse occurred in 10 cases. This shows a trend in the same direction as Stemberger's (1991a) finding, although he found that nasals asymmetrically replaced stops at a rate of about 2 to 1 (29/14). Fewer anticipations and perseverations occurred in this study, which may affect the comparison.

In sum, the findings of Experiment 1 were that significantly more errors occurred for nasals and voiced stops than nasals and voiceless stops. These results are in accord with those of Stemberger (1991b). The replication of Stemberger's results is important because it strengthens the claim that nasals interact in more errors with voiced stops than voiceless stops, which is a key contrast in the context of speech error research exploring connections to nasal consonant harmony. Further, it verifies that the SLIPS technique as applied in this series of experiments is capable of deriving known results. Theoretical implications are addressed in the general discussion.

TABLE 3
Number of errors as a function of voicing, Experiment 1

	Place	*C-Exchange*	*W-Exchange*	*Anticipation*	*Perseveration*	*False Start*	*Total*
Voiced stop	Bilabial (m-b/b-m)	23	3	5	3	13	47
	Alveolar (n-d/d-n)	23	5	8	4	8	48
Total		46	8	13	7	21	95
Voiceless stop	Bilabial (m-p/p-m)	12	5	2	0	10	29
	Alveolar (n-t/t-n)	25	2	3	1	4	35
Total		37	7	5	1	14	64

EXPERIMENT 2: PLACE OF ARTICULATION

Experiment 2 investigated the hypothesis that there will be more errors for nasals and voiced stops with the same place than nasals and voiced stops with difference place. A SLIPS experiment by Stemberger (1991b) examined the effect of place in errors for stops and fricatives in English. For the theoretical issues at hand, it is necessary to investigate nasal-stop pairs.

Method

Subjects. Subjects were 35 undergraduates at the University of Southern California who were native speakers of English. There were 23 subjects enrolled in psychology courses, who received course credit for participation, and 12 others, who received monetary compensation. Subjects who participated in Experiment 2 did not participate in Experiment 1.

Materials. The stimuli were designed in much the same way as for Experiment 1. There were 160 critical pairs with phonological priming that followed the same scheme as before. All words were real words of English of the form consonant-vowel-consonant. Critical words became real words under an exchange, anticipation or perseveration error involving the initial consonants. Critical pair composition was controlled for the factors in (7), fully crossed – factor (i) is the one under investigation. The critical pairs are included in Appendix A. Randomisation of critical pair order and of filler pair distribution was the same as in Experiment 1 and subject to the same restrictions. The number of filler pairs and cued fillers was also the same.

(7) *Experiment 2: Controlled factors in critical pairs*

i. Place: word pairs containing initial nasal and voiced stop with the same place vs. initial nasal and voiced stop with different place (*m*/*b* vs. *m*/*d* and *n*/*d* vs. *n*/*b*).
ii. Nasal place: bilabial vs. alveolar nasal.
iii. Order: nasal-initial word first vs. oral stop-initial word first.
iv. Vowel: same vs. different vowels within words in a pair.
v. Earliness: word pair cued in first half of the experiment or the second half.

Subject to the controlled factors in (7), critical words were selected to minimise differences in frequency within contrasts for [m] and for [n]. Mean word frequencies were as follows (*SD* in parentheses). In pairs for the *m*/*b* contrast, 289.8 (367.6) for words with initial [b] and 221.2 (254.4) for initial [m]. In word pairs for the *m*/*d* contrast, 343.3 (729.2) for words with initial [d] and 466.6 (590.3) for initial [m]. For the *n*/*d* contrast, 281.2 (766) for initial [d] and 295.2 (343.7) for initial [n]. In word pairs for the *n*/*b* contrast, 462.7 (493.5) for initial [b] and 242.8 (363.7) for initial [n]. Like Experiment 1, words within a critical pair were more closely matched for lexical frequency (within pairs with [m], mean $SD = 59\%$ of the standard deviation for the entire set of words used in critical pairs with [m] in the experiment, and in pairs with [n], mean $SD = 58\%$ of that for the entire set of words used in pairs with [n]).

As in Experiment 1, each critical pair appeared twice in the list, once with the nasal-initial word first and once with the order reversed. Some words were used in two separate critical word pairings in order to meet the controlled factors in (7), and all appeared in the list six times. Balance for word repetition throughout the list was partly controlled for by the balances instituted in each half of the list. The list was further checked in the same ways as in Experiment 1, confirming that repetition exposure was overall comparable within the conditions. Starting with one half of the list, means for critical words used in pairs containing a bilabial nasal were as follows (*SD* in parentheses): *m*/*b* at the list quarter point 1.76 (1.15) and at half point 3.07 (0.53) vs. *m*/*d* at quarter 1.32 (1.22) and at half 2.89 (0.5). For words used in pairs containing an alveolar nasal, means for *n*/*d* were 1.55 (0.95) at quarter and 3 (0.54) at half vs. *n*/*b* 1.66 (0.86) at quarter and 3.07 (0.46) at half. For each critical pair in the second half, the number of previous occurrences of each critical word was counted. Means for critical pairs with [m] were 4 (0.78) for *m*/*b* vs. 3.95 (0.85) for *m*/*d*. For pairs with [n], means were 4.15 (0.86) for *n*/*d* vs. 4 (0.88) for *n*/*b*. Repetition priming thus did not appear likely to asymmetrically influence the conditions under study.

Procedure. The procedure was the same as in Experiment 1.

Results and discussion

Subjects' responses were coded in the same way as in Experiment 1. There were 132 initial consonant errors, for a mean error rate of 2.2%. There were 91 errors in critical pairs containing an initial nasal and voiced stop with the same place (either order) and only 41 errors in pairs with an initial nasal and voiced stop with different place (either order). This asymmetry was found to be significant, using a Mann–Whitney U test. Eighteen out of thirty-five subjects produced more errors in nasal-voiced stop pairs with the same place of articulation (only six subjects showed the reverse trend, eleven subjects produced the same number of errors in each condition), $U(1) = 429$, $p < .05$. In addition, errors were typically more common for critical pair items containing initial stops with the same place than for ones containing stops with different place, $U(1) = 400$, $p < .001$. Table 4 shows the data broken down by same/different place and nasal place. In anticipations and perseverations, there were 20 errors where a nasal substituted for an oral stop and 5 cases of the reverse. This correlates with the asymmetry that Stemberger (1991a) observed, although the ratio is not identical, possibly due to the lower number of relevant errors in this study.

The primary result of Experiment 2 is thus that same place of articulation significantly increases the likelihood of an error involving initial nasals and voiced stops. In this experiment the proportion of consonant exchange errors for consonants with different place is relatively low (22%), while the percentage of exchange errors in pairs with same place is higher (46%). Stemberger (1991a) found that SLIPS-generated errors yield about 50% exchange errors for some contrasts and about 30% for others. The stop-nasal contrast was one that showed a higher rate of exchange errors in Stemberger's study, although he only examined place-matched pairs. The lower rate of exchange errors for nasal-stop pairs with different place is suggestive that having the same place of articulation is a factor in generating a higher exchange error rate.

In view of Stemberger's (1991b) study of labial-labial and alveolar-alveolar pairs in speech errors, the data were further analysed along these lines. Using an ANOVA, no significant difference was found in the number of errors for [m] vs. [n], $F(1, 34) = 0.35$, $p = .56$ with subject as random factor, $F(1, 76) = 0.25$, $p = .62$ with item as random factor, nor was a significant interaction found between factors of place (same/different) and nasal place (*m*/*n*), $F(1, 34) = 0.11$, $p = .74$ with subject as random factor, and $F(1, 76) = 0.11$, $p = .74$ with item as random factor. In accord with the Mann–Whitney U test, an ANOVA found that the place factor was significant, $F(1, 34) = 12.74$, $p = .001$ with subject as random factor, and $F(1, 76) = 17.17$, $p < .001$ with item as random factor. Both labials and alveolars therefore show the same trend: if place is shared in a nasal-voiced

TABLE 4
Number of errors as a function of place, Experiment 2

	Nasal Place	C-Exchange	W-Exchange	Anticipation	Perseveration	False Start	Total
Same place	Bilabial (m-b/b-m)	23	8	3	6	8	48
	Alveolar (n-d/d-n)	19	4	7	5	8	43
Total		42	12	10	11	16	91
Different place	Bilabial (m-d/d-m)	3	9	1	0	8	21
	Alveolar (n-b/b-n)	6	5	0	3	6	20
Total		9	14	1	3	14	41

stop pair there are more errors than if the place is different. The lack of a significant effect of nasal place agrees with Stemberger's (1991b) finding that place-matched nasal-oral stop pairs do not show a difference in error rate across bilabials and alveolars. Note that as this issue was not this study's primary focus, frequency across the nasal place of articulation contrast was not emphasised in the experiment design.

Returning to the context of nasal consonant harmony, it is relevant that in those patterns both labials and coronals show a capacity to interact solely with place-matching consonants. The speech error data from Experiment 2 show gradient trends in this direction.

EXPERIMENT 3: MANNER: PROPERTY WEIGHTING

Experiment 3 investigated the hypothesis that there will be more errors involving nasals and approximants with (partially) same place than for nasals and voiceless stops with the same place.

Method

Subjects. Subjects were 35 undergraduates at the University of Southern California who were native speakers of English. There were 25 subjects enrolled in psychology courses, who received course credit for participation, and 10 others, who received monetary compensation. Subjects who participated in Experiment 3 did not participate in Experiments 1 or 2.

Materials. The stimuli were designed along the same lines as the first two experiments. There were 160 critical pairs (see Appendix A) with phonological priming structured as before. All words in the list had the form consonant-vowel-consonant, and were real English words. Critical words became real words under an initial consonant exchange, anticipation or perseveration error. Critical pairs in Experiment 3 were controlled for the factors in (8), fully crossed. The number of filler pairs and number of fillers cued was as in Experiments 1 and 2. Randomisation of critical pair order and of the distribution of filler pairs was the same as before.

(8) *Experiment 3: Controlled factors in critical pairs*

i. Manner: word pairs with initial nasal and liquid vs. initial nasal and voiceless stop (*n/l* vs. *n/t* and *m/r* vs. *m/p*).
ii. Nasal place: bilabial vs. alveolar nasal.
iii. Order: nasal-initial word first vs. oral consonant-initial word first.
iv. Vowel: same vs. different vowels within words in a pair.
v. Earliness: word pair cued in first half of the experiment or the second half.

The manner factor involves the conditions examined in this experiment. Among the approximants of English, liquids were selected for examination in this study. This choice was made for two reasons. First, liquids are more similar to nasals than glides in the sense that they are not vocoids (the class of vowels and glides) and they have lower sonority (i.e., loudness, at least in syllable onset). Second, liquids form a sub-category (i.e., a natural class) within the larger category of approximants. As mentioned earlier, in some patterns of nasal consonant harmony, [l] is the only approximant that is reported to be affected. As [l] is a liquid, consonants belonging to the sub-category of liquids were therefore selected for this research. The nasal/liquid contrasts examined were *n/l* and *m/r*. It is possible that some speakers might produce [l] as dental and [n] as alveolar but both are produced as coronal. Although [r] is produced with a primary constriction in the coronal region, many English speakers also produce a labial articulation in the form of lip rounding (Ladefoged, 1993, p. 65). Due to its labialisation, [r] is the closest liquid of English in terms of place for [m].[13] Note that as English [r] is not typical of non-lateral liquids in most languages, it does not form a precise comparison with the consonants usually involved in nasal consonant harmony. Experiment 2 determined that there are more errors between nasals and consonants that match in place of articulation. Thus, if the

[13] Among English liquids, [r] is the closest available to compare with [m]. English [r] patterns with glides in some respects. Another experiment could test nasals and the wider set of (partially) place-matched approximants (liquids and glides). In that case the labiovelar glide [w] would be another available labial segment to pair with [m].

imperfect match in place for [r] and [m] were to have any effect, it would be expected to reduce the number of errors involving these consonants. If more errors were nevertheless found between *m/r* than *m/p*, that would suggest an even stronger tendency for nasals to participate in more errors with liquids than voiceless stops.

Subject to the controlled factors in (8), critical words were selected to minimise differences in frequency within contrasts for [m] and for [n]. Mean frequencies were as follows (*SD* in parentheses). In word pairs for the *m/r* contrast, 502.8 (493.3) for words with initial [r] and 345.7 (496.7) for initial [m]. For the *m/p* contrast, 202.8 (217) for words with initial [p] and 363.8 (482.8) for initial [m]. In word pairs for the *n/l* contrast, 336.8 (708) for initial [l] and 323.9 (367.2) for initial [n]. For the *n/t* contrast, 200.1 (229.2) for initial [t] and 271.1 (300.2) for initial [n]. As in the first two experiments, lexical frequency was tighter within word pairs (within critical pairs with initial [m, r, p] mean $SD = 59\%$ of standard deviation for the entire set of critical words beginning with [m, r, p] used in the experiment, and within word pairs with [n, l, t], mean $SD = 61\%$ of that for the set of critical words with [n, l, t]).

As in Experiments 1 and 2, each critical pair appeared twice in the word list, with words in opposite order, and some words were used in two separate critical word pairings. All words appeared in the word list six times. The two halves of the list were balanced on the whole as a result of control for factors (i)–(iv). As in Experiments 1 and 2, the word list was further examined to check for balance of word repetition. Exposure was overall even within the conditions. Taking one half of the list first, means (*SD* in parentheses) for words in critical pairs with [m] were as follows. For *m/r* 1.58 (1.12) at the list quarter point and 2.77 (0.72) at half point vs. *m/p* 1.5 (0.76) at quarter and 2.96 (0.66) at half. For words in critical pairs with [n], means for *n/l* were 1.33 (0.92) at quarter and 3.04 (0.76) at half vs. *n/t* 1.52 (0.77) at quarter and 2.96 (0.46) at half. For each critical pair in the second half, the number of previous occurrences of each critical word was counted. For words in critical pairs with [m], means were 3.85 (1.05) for *m/r* vs. 4.05 (0.82) for *m/p*. For words in critical pairs with [n], means were 3.85 (0.92) for *n/l* vs. 4.03 (0.8) for *n/t*. Repetition priming thus did not appear likely to asymmetrically affect the conditions.

Procedure. The procedure was the same as in Experiments 1 and 2.

Results and discussion

Subjects' responses were coded in the same way as in Experiments 1 and 2. There were 157 initial consonant errors, yielding a mean error rate of 2.8%. There were 103 errors for initial nasals and liquids (either order) vs. 54 errors for initial nasals and voiceless stops (either order). This difference was found to be significant, using a Mann–Whitney *U* test. Twenty out of thirty-five subjects made more errors with nasals and liquids than nasals and voiceless stops (nine subjects showed the reverse trend, six subjects produced the same number of errors in each condition), $U(1) = 418$, $p < .05$. Similarly, there were generally more errors made with critical pair items with an initial nasal and liquid than with ones containing an initial nasal and voiceless stop, $U(1) = 502.5$, $p < .01$. The results are reported in Table 5 as a function of oral consonant manner and nasal place. The trend for more errors involving nasals and liquids is found for both [m] and [n]. The percentage of consonant exchange errors is high in both conditions (54% in nasal-liquid pairs, 57% in nasal-voiceless stop pairs). This is compatible with Stemberger's (1991a) finding that SLIPS experiments generate more exchange errors in contrasts with stops that have a difference in manner.[14] It also is consistent with the observation from Experiment 2 that a higher rate of exchange errors is prone to occur when place of articulation is shared. In the contrasts examined in Experiment 3, place was at least partially matched in all cases. Among anticipations and perseverations, a nasal substituted for an oral consonant in 8 errors and the reverse occurred in 13 cases. This departs from the tendency for nasals to replace oral consonants seen in Experiments 1 and 2 and found by Stemberger (1991a). The small number of relevant errors here makes it difficult to draw any conclusions, but further research may illuminate whether a manner-sensitive difference exists.

To summarise, the findings of Experiment 3 are that nasals participate in more initial consonant errors with (partially) place-matched liquids than with place-matched voiceless stops. Previous studies have noted that stricture and voicing features are among those most often shared by consonants that participate together in an error (e.g., MacKay, 1970a; Shattuck-Hufnagel & Klatt, 1979). The results of this experiment add further delineation, suggesting that nasals and approximants, which are both voiced and sonorant, are more prone to interact than nasals and voiceless stops, which have identical stricture. Returning to the partial place identity, it is noteworthy that more errors occurred for *m/r* than *m/p* even though [m] and [r] have only a partial match for place. It is conceivable that the greater number of errors for *m/r* is a consequence of their both being sonorant consonants. However, if the shared labial articulation in [m] and [r] contributed to their similarity, this would be a case where a so-called

[14] It is an interesting question whether word exchanges show the same effects as consonant exchanges. The results of Experiment 3 suggests this might be the case, although Experiments 1 and 2 could suggest otherwise. As mentioned above, some errors classified as word exchanges are ambiguous between a word reversal and simultaneous reversal of the initial and final consonants. The issue merits investigation in another study.

TABLE 5
Number of errors as a function of manner, Experiment 3

	Nasal Place	*C-Exchange*	*W-Exchange*	*Anticipation*	*Perseveration*	*False Start*	*Total*
Liquid	Bilabial (m-r/r-m)	30	10	1	1	7	49
	Alveolar (n-l/l-n)	26	3	5	3	17	54
Total		56	13	6	4	24	103
Voiceless stop	Bilabial (m-p/p-m)	17	4	3	2	2	28
	Alveolar (n-t/t-n)	14	3	3	3	3	26
Total		31	7	6	5	5	54

predictable, 'allophonic' feature, namely [Labial] in [r], contributes to segmental similarity. This possibility resonates with Stemberger's (1991b) finding that allophonic velarisation in English /l/ is relevant in speech errors (note also Stemberger, 1991b and Frisch et al., 2004 on redundant voicing in sonorants).

GENERAL DISCUSSION

General hypothesis

These experiments explored the hypothesis that the sounds that participate in more speech errors involving nasals would show a higher tendency to participate in nasal consonant harmony. This hypothesis was borne out for each factor examined. Assuming that greater phonological similarity increases the likelihood for phonological units to interact (e.g., Frisch, 1996; Fromkin, 1971; Hansson, 2001; MacKay, 1970a; Rose & Walker, 2004), this study contributes support for a convergence in similarity across language performance and phonology.

Stemberger (1992a) observed that experimentally elicited speech errors and naturalistic data show considerable convergence. Nevertheless, Meyer (1992) has suggested that experimentally generated error data should be validated by comparison with errors in naturally occurring speech. In this regard, two natural speech error corpora were examined: the MIT corpus reported by Shattuck-Hufnagel and Klatt (1979), which lists 1620 consonant substitution and exchange errors, and the corpus reported by Stemberger (1991a), which lists 1273 consonant substitution errors.

Error counts for the relevant consonant pairs are given in Table 6 for the MIT corpus and Table 7 for Stemberger's corpus. 'Predicted' error counts report predicted distributions based on chance. After Stemberger (1992b), chance was estimated using a method that controls for how likely a given consonant is to participate in an error, either as the *target* (the consonant mispronounced) or as the *source* (the actual mispronunciation) (see also Klatt, 1968; Dell, 1984; Shattuck-Hufnagel, 1986; Stemberger, 1991b). To compute predicted error counts, first the likelihood of an error involving each particular consonant pair was calculated. Taking *m/b* in the MIT corpus as an example, [b] was the target in 78 errors and [m] was the source in 92. The estimated chance that [b] would be misproduced as [m] is 78/1620 × 92/1620, or 0.27% of all errors (= 4.4 errors). Conversely, [b] was the source in 70 errors and [m] the target in 97. The estimated chance that [m] would be misproduced as [b] is 97/1620 × 70/1620, or 0.26% (= 4.2 errors). Thus, *m/b* are estimated to participate in 8.6 errors by chance.

Comparing pairs, such as *m/b* vs. *m/p*, necessitates calculating their predicted relative distribution of errors: 8.6 errors are predicted for *m/b* and 12.11 for *m/p*; hence 1.41 times as many errors are predicted for *m/p* than *m/b*. The total number of observed errors for *m/b* and *m/p*, which is 34, is then divided according to this proportion, giving a predicted distribution of 14.14

TABLE 6
Analysis of speech errors from MIT corpus, reported in Shattuck-Hufnagel and Klatt (1979)

Factor	*Nasal place*	*Consonant pairs*		*Chi-square*	*Probability*
Voicing	*m (bilabial)*	m/b	m/p		
	Actual	24	10		
	Predicted	14.14	19.86	χ^2 (1) = 11.77	$p < .001$
	n (alveolar)	n/d	n/t		
	Actual	15	10		
	Predicted	10.13	14.87	χ^2 (1) = 3.94	$p < .05$
Place	*m (bilabial)*	m/b	m/d		
	Actual	24	6		
	Predicted	14.79	15.21	χ^2 (1) = 11.31	$p < .001$
	n (alveolar)	n/d	n/b		
	Actual	15	4		
	Predicted	9.64	9.36	χ^2 (1) = 6.04	$p < .05$
Manner	*m (bilabial)*	m/r	m/p		
	Actual	20	10		
	Predicted	17.07	12.93	χ^2 (1) = 1.17	$p = .28$, *ns*
	n (alveolar)	n/l	n/t		
	Actual	41	10		
	Predicted	29.13	21.87	χ^2 (1) = 11.28	$p < .001$

TABLE 7
Analysis of speech errors from Stemberger's corpus, reported in Stemberger (1991a)

Factor	*Nasal place*	*Consonant pairs*		*Chi-square*	*Probability*
Voicing	*m (bilabial)*	m/b	m/p		
	Actual	14	8		
	Predicted	9.03	12.97	χ^2 (1) = 4.61	$p < .05$
	n (alveolar)	n/d	n/t		
	Actual	16	11		
	Predicted	9.18	17.82	χ^2 (1) = 7.68	$p < .01$
Place	*m (bilabial)*	m/b	m/d		
	Actual	14	1		
	Predicted	7.02	7.98	χ^2 (1) = 13.05	$p < .001$
	n (alveolar)	n/d	n/b		
	Actual	16	2		
	Predicted	9.56	8.44	χ^2 (1) = 9.25	$p < .01$
Manner	*m (bilabial)*	m/r	m/p		
	Actual	6	8		
	Predicted	7.82	6.18	χ^2 (1) = 0.96	$p = .33$, *ns*
	n (alveolar)	n/l	n/t		
	Actual	24	11		
	Predicted	17.3	17.7	χ^2 (1) = 5.13	$p < .05$

errors for *m/b* and 19.86 for *m/p*. Predicted and observed distributions were compared using a chi square test. These results are included in Tables 6 and 7. For the most part, the naturalistic error data show the same trends as the experimental results. In both corpora, there were significantly more errors for nasals and voiced stops than nasals and voiceless stops, and more errors for nasals and voiced stops with the same place than with different place. Further, *n/l* showed more errors than *n/t*; but there was no significant difference in predicted and actual errors for *m/r* vs. *m/p*. The latter result could be because [r] has error patterns that are quite different from [p]. For example, [r] has a high error rate with [l], which might decrease the proportion of errors for *m/r*. Apart from this sub-case, the results uniformly suggest that the contrasts which present a higher level of interaction in SLIPS errors also show an increased interaction in naturalistic errors.

Consonants that participated in more speech errors in the experiments are interpreted as more similar than those that participated less. As phoneme frequency can also impact error rate (e.g., Dell, 1986; Levitt & Healy, 1985; Stemberger, 1991a, 1991b), the data were examined post hoc for possible phoneme frequency effects. Stemberger (1991b) noted that lower frequency phonemes should be involved in more errors when they are the target, but phonemes that are the source of an error show higher error rates if they are higher frequency (Treisman, 1978) or they show no effect of frequency

TABLE 8
Phoneme error rates and frequency

	Phoneme	Error rate (%)	Frequency (%)		
			Denes	Shattuck-Hufnagel and Klatt	Mean
Experiment 1	p	2.1	2.9	5.0	3.95
	b	3.4	3.4	2.9	3.15
	m	2.7	5.4	5.3	5.35
	t	2.5	13.8	12.9	13.35
	d	3.4	6.9	7.9	7.4
	n	3.0	11.7	9.5	10.6
Experiment 2	b (with m)	3.2	3.4	2.9	3.15
	d (with m)	1.4	6.9	7.9	7.4
	b (with n)	1.4	3.4	2.9	3.15
	d (with n)	2.9	6.9	7.9	7.4
Experiment 3	p	2	2.9	5.0	3.95
	r	3.5	4.6	7.3	5.95
	m	2.8	5.4	5.3	5.35
	t	1.9	13.8	12.9	13.35
	l	3.9	6.1	7.7	6.9
	n	2.9	11.7	9.5	10.6

(MacKay, 1973). The error rate by consonant for each experiment is given in Table 8 together with the percentage of consonants each phoneme accounts for in the frequency counts of Denes (1963) and Shattuck-Hufnagel and Klatt (1979) and their mean.

Voiceless [t] has a greater mean frequency than [d]. Also, [p] has a slightly higher mean frequency than [b], although in Denes (1963), [b] is slightly more frequent than [p]. The overall higher frequency of voiceless stops is compatible with the finding that they participate as targets in fewer errors with nasals than voiced stops do. Setting aside exchange errors, there were 21 errors in which a voiced stop was the target vs. only 11 where a voiceless stop was the target. However, in errors where the oral stop was the source of the error, phoneme frequency could not be responsible for the higher error rate in nasal-voiced stop pairs. Apart from exchanges, there were 20 errors in which a voiced stop was the source vs. 9 in which a voiceless stop was the source. These error patterns were thus not determined by phoneme frequency.

Experiment 2 compared nasal and oral consonant pairs with same vs. different place. Results in Table 8 are broken down by the voiced stop's paired nasal. Mean phoneme frequency for voiced stops predicts a higher error rate for pairs in which /b/ is the target of an error vs. /d/. When paired with [m], the errors involving [b] as a target exceeded that of [d] (11 errors vs.

4, excluding exchanges), but the reverse was observed in pairings with [n] (6 errors for [b] vs. 16 for [d], excluding exchanges). The observed error rates were thus not uniformly consistent with a phoneme frequency effect but instead correlate with a pattern where more errors occurred in pairs of nasals and voiced stops with same place than in corresponding pairs with different place.

For Experiment 3, mean phoneme frequencies predict generally more errors involving [p] than [r] and more involving [l] than [t]. While the error rate for [l] did exceed that for [t], there were more errors involving [r] than [p]. This is also true if we focus on errors in which the oral consonant was a target. There were more errors involving [l] and [r] (14 and 7 respectively, excluding exchange errors) vs. ones involving [t] and [p] (1 and 3, respectively). Again, the error pattern does not regularly conform with that predicted by a phoneme frequency effect.

Another issue bearing on phonological similarity concerns ambiguity for the level of phonological structure at which errors operate. For example, if the errors in question involved segment exchanges and substitutions, then an exchange of any two segments should incur the same 'cost' in terms of units re-ordered. But if they exchanged gestures, then an error re-ordering two gestures might incur a greater cost than one re-ordering a single gesture, which could affect the error pattern. Many studies have argued that segments are the primary units involved in phonological errors (e.g., Fromkin, 1973; Shattuck-Hufnagel, 1983; Shattuck-Hufnagel & Klatt, 1979; note also Berg, 1985). However, certain more recent research has argued that the occurrence of subsegmental errors, some of which may be partial or gradient (and sometimes inaudible), is more prevalent than previously understood (Frisch & Wright, 2002; Goldrick & Blumstein, 2006; Goldstein, Pouplier, Chen, Saltzman, & Byrd, 2007; Guest, 2001; Mowrey & MacKay, 1990; Pouplier, 2003a, 2003b; see also Stemberger, 1991b; cf. Stemberger, 2007, on the issue of gradient errors). The present study measured only errors that produced audibly perceptible results. Gradient errors with inaudible occurrences of motor activity were thus not included. Among the audible errors there is reason to believe that the units manipulated most often were segments. In cases where interacting segments differed by more than one feature, virtually all errors for initial consonants were an exchange or substitution affecting all properties. There were very few errors in which, for example, *p/m* was erroneously produced as *b/m*, substituting only voicing ($n = 3$ in Experiment 1 (for voicing), $n = 9$ in Experiment 2 ($n = 5$ for Place, $n = 4$ for [$\pm$ nasal]), $n = 0$ in Experiment 3). This agrees with previous findings that (non-gradient, audible) feature errors are rare, and it suggests that the error patterns found in this research were not determined by differences in the number of units undergoing movement.

Further support comes from Experiment 3. Nasals and liquids differ by more articulatory properties than nasals and voiceless stops, but they showed greater interaction. The pair *m*/*r* differs in nasality, stricture, coronality, and (for some speakers) retroflexion, and *n*/*l* differs in nasality, laterality, and stricture. The pairs *m*/*p* and *n*/*t* differ only in nasality and voicing. If the errors were primarily exchanging and substituting gestural units, and errors affecting fewer gestures were more frequent, then there should instead have been more errors for *m*/*p* and *n*/*t*.

Calculating phonological similarity. While segments with greater phonological similarity frequently match in more gestures, research has found that the computation of phonological similarity is more complex. Accordingly, some predictions of the feature classes similarity metric proposed by Frisch et al. (2004) are considered. The speech error results are examined first, using similarity values for English calculated by Frisch (1996). Identical segments' rating is 1. Experiment 1 found more errors for nasals and voiced stops than nasals and voiceless stops. Consistent with these results, the similarity rating for nasals and voiced stops (*m*/*b*, *n*/*d*), averaged across places of articulation, is .39, while the rating for nasals and voiceless stops (*m*/*p*, *n*/*t*) is just .19. In Experiment 2 there were more errors for nasals and voiced stops with same place than nasals and voiced stops with different place. This correlates with the averaged similarity rating of .39 for nasals and voiced stops with same place vs. .12 for nasals and voiced stops with different place (*m*/*d*, *n*/*b*). Experiment 3 obtained more errors for nasals and liquids than for nasals and voiceless stops. The average for pairs *m*/*r* and *n*/*l* is .49, which exceeds the .19 rating for nasals and voiceless stops with same place, again consistent with the experimental findings. The metric further correctly predicts the possibility of somewhat more errors for place-matched nasals and voiceless stops (.19 similarity rating; 2.28% error rate in Experiment 1, 1.93% in Experiment 3) than for nasals and voiced stops with different place (.12 similarity rating; 1.46% error rate in Experiment 2). Also, the metric correctly predicts somewhat more errors for nasals and (partially) place-matched approximants (.49 similarity rating; 3.68% error rate in Experiment 3) than for nasals and place-matched voiced stops (.39 similarity rating; 3.39% error rate in Experiment 1, 3.25% in Experiment 2), but such contrasts remain to be examined within a single experiment.

Turning to nasal harmony, similarity ratings were examined for relevant consonants in Kikongo and Ganda. Features used in the calculations were {[Consonantal], [Sonorant], [Continuant], [Voice], [Labial], [Coronal], [Dorsal], [Nasal], [Anterior]}.[15] In Kikongo, voiced stops and approximants

[15] The feature [Anterior] was used only for similarity calculations for Ganda.

participate in nasal harmony, whether they share place or not, but voiceless stops do not participate. In agreement with this pattern, Kikongo's average similarity rating for nasal-voiced stop pairs across same and different place is .30, but only .17 for nasal-voiceless stop pairs. Also, the average for nasals paired with the approximant [l] is .28, which exceeds the .17 rating for nasals and voiceless stops. In Ganda, voiced stops and approximants interact with nasals in nasal harmony if they share place. Voiceless stops with same place also interact with nasals, but in a more limited way – only when the nasal precedes the stop. On the other hand, nasals and voiced stops with different place can generally co-occur (subject to some limitations). The pattern is consistent with the similarity ratings given by the feature classes metric. Pairs of place-matched nasals and voiced stops (and approximant variants) have an average of .37, which exceeds the .21 average for nasal-voiceless stop pairs with the same place, which in turn is slightly more than the .17 average for nasal-voiced stop pairs with different place.

The scaling of place-matched nasal-voiceless stop pairs as more similar than nasal-voiced stop pairs with different place raises an issue. For Kikongo, the feature classes metric rates the place-matched nasal-voiceless stop group as higher at .21 than nasal-voiced stop pairs with different place at .13. However, in Kikongo the latter pairs interact in nasal harmony but not the former. Although this could be interpreted as a shortcoming of the similarity computation, that is doubtful. The inventories of Kikongo and Ganda are not vastly different. In both languages, nasal harmony affects voiced stops with the same place. In Kikongo it also affects voiced stops with different place, but not voiceless stops with the same place, while Ganda shows the reverse. Yet an objective similarity metric is unlikely to rank these groups differently in these languages. Assuming that the similarity ratings are on target, another factor could also be relevant in determining participants in nasal consonant harmony. Alternatively, similarity could function more coarsely than the numeric scale yields. In the latter case, the similarity scaling with respect to consonant harmony (and possibly other phonological processes) would consist of tiers for nasal-oral stop pairs (cf. (4a)) The top tier would contain place-matched nasal-voiced stop pairs, e.g., *m/b, n/d*. The second tier would contain place-matched nasal-voiceless stop pairs, e.g., *m/p, n/t*, and nasals/voiced stop pairs with different place, e.g., *m/d, n/b.* Nasal harmonies that reach into the second tier could vary according to the property selected: all voiced stops or all stops with same place. Thus, while the feature classes metric computes a fine-grained similarity scale, which could be relevant in other areas or processes, harmony phenomena would show more coarse-grained effects (for related observations, see e.g., Flemming, 2001; Pierrehumbert, 1990).

In sum, the feature classes similarity computation is generally consistent with English speech error patterns and nasal harmony in Kikongo and

Ganda (but harmony shows less fine-grain). Issues nevertheless remain. One matter involves asymmetries in similarity and errors. A prominent error asymmetry was found in Experiment 2 only, with nasals more likely to replace oral stops. The generality of asymmetries in nasal/oral consonant contrasts and whether they are related to the strong tendency for nasal harmony to produce nasals rather than oral consonants warrants further study. Another area concerns other factors that affect (non-)participation in harmony. While many sounds rated as comparatively similar by the feature classes metric show a propensity to interact in consonant harmony in certain languages, harmony for place is an exception. Voiceless stops *p*/*t*/*k* have an average similarity of .36 in English and voiced *b*/*d*/*g* an average similarity of .34. Yet harmony for primary place ([Labial], [Coronal], etc.) is largely unattested in adult languages (Hansson, 2001; Rose & Walker, 2004).[16] This suggests that another factor inhibits harmony for primary place (see Rose & Walker, 2004).

Consonant harmony. This study's results are consistent with the proposal that consonant harmony has functional origins in language production (Hansson, 2001; Rose & Walker, 2004; Walker, 2000a,b). Under the view considered here, the functional basis does not represent a conscious intention of the speaker but it exerts influence on language change and shapes certain synchronic phonological processes through constraints grounded in production. Related work on effects of speech production and perception in phonology includes Frisch et al. (2004), papers in Hayes, Kirchner, and Steriade (2004) and Hume and Johnson (2001), and citations therein.

Minimally different sounds show increased interaction in speech planning errors. Such errors frequently render sounds identical, e.g., *when does the mus for Monticello leave?* (*mus* for *bus*) (Shattuck-Hufnagel & Klatt, 1979). This connects with the proposed functional grounding for consonant harmony. By requiring that similar but different nasal and oral consonants match in nasality, the grammar pre-emptively reduces the potential for an error involving nasalisation.

Similar speech sounds can also result in speech execution errors, which may be gradient and/or phonotactically ill-formed (Frisch & Wright, 2002; Goldstein et al., 2007; Goldrick & Blumstein, 2006; Mowrey & MacKay, 1990; Pouplier, 2003a, 2003b). Research in this area is still developing. It remains to be established whether errors in articulatory implementation show the range of properties witnessed in speech planning that parallel consonant harmony. Further, Stemberger (2007) has questioned whether certain gradience in performance should qualify as 'speech errors'. At the same time, the observation that similar but different sounds cause difficulties

[16] See Hansson (2001) for some possible cases of consonant harmony for major place.

at this level of production reinforces a basis for consonant harmony in production factors. Also pertinent is that execution errors often manipulate subsegmental units. Goldstein et al. (2007) found that gradient errors frequently show intrusion of a gesture from one segment on another, often without reduction of the target gesture in the affected segment (see also Pouplier, 2003a, 2003b). This repetition of subsegmental units in production finds a correlate in consonant harmony, which requires that a feature be replicated in similar segments.

Taken together, speech error research points to a finding that similar but different sounds pose difficulty which can be improved by a move towards identity. This is captured in spreading-activation models, in which phonological encoding of a word or phrase involves node activation for each phonological element. Activation spreading causes formation of a strong connection between minimally different sounds, increasing the chance of an error (e.g., Dell, 1984, 1986; MacKay, 1987; Stemberger, 1985a, 1985b). The difficulty is in coordinating differences in highly similar sounds. Matching their properties is a means of resolving the problem.

The phonological similarity of interacting segments and their shift to closer identity is not the only basis for the hypothesised roots of consonant harmony in production factors. Other parallels that exist between speech errors and the typology of consonant harmony include action-at-a-distance, directionality effects, and 'palatal bias' effects (Hansson, 2001; Rose & Walker, 2004). This bears on an alternative interpretation under which speech planning and phonological processes each draw on the same instantiation of similarity but the former does not influence the latter. While that interpretation is also consistent with this study's findings, the convergence of the above parallels is not predicted if language production and consonant harmony are unrelated.

Dissimilation raises related issues. Although speech errors may involve a shift towards identity, they can also cause dissimilation. Stemberger (1991a) noted quantitative support that phoneme repetition increases the error rate. More generally, psycholinguistic research has shown that repetition can produce difficulties in speech production and perception processing (for an overview, see Frisch, 2004; see also Berg, 1998; Boersma, 1998; Dell, 1984; Frisch et al., 2004; MacKay, 1970b, 1987; Miller & MacKay, 1994; Sevald & Dell, 1994; Shattuck-Hufnagel, 1979). Alongside phonological phenomena that cause harmony or repetition, patterns occur that favour dissimilation or repetition avoidance (e.g., Frisch, 2004; MacEachern, 1999; Walker, 2000b; Yip, 1997). Like consonant harmony, repetition avoidance phenomena show parallels with speech errors. Both show potential for interactions of non-adjacent segments. Also, similarity is relevant in determining which sounds must disagree for some property (e.g., MacEachern, 1999; McCarthy, 1988; Padgett, 1995; Pierrehumbert, 1993; Suzuki, 1998; see Frisch, 1996, 2004;

Frisch et al., 2004 for discussion in the context of the role of perception processing). The resulting picture suggests that grammars may differ in emphasising repetition (e.g., harmony) or its avoidance (e.g., dissimilation). A generally common theme is a dispreference for highly similar but different sounds. Consonant harmonies cause a shift towards identity, and some dissimilation phenomena exempt identical segments (Frisch, 2004; MacEachern, 1999).[17]

Future research could explore connections between error patterns and harmony for other features. A tongue twister study by Rose and King (in press) has already examined Ethiopian Semitic languages, finding a higher error rate for pairs of voiceless consonants that do not obey the languages' laryngeal consonant harmony constraint. Extensions to vowel harmony could also be explored. Research on consonant harmony and dissimilation could examine asymmetries in the features involved. For example, restrictions involving primary place of articulation present themselves largely, perhaps entirely, as repetition avoidance effects. Errors in Ethiopian Semitic languages that show a constraint on consonants with the same place of articulation have been investigated by Rose and King (in press), and further studies would be valuable.

The asymmetry involving place features is striking given the occurrence of consonant harmony for place of articulation in the developing language of many children (about 50% of English-learning children, Bernhardt & Stemberger, 1998; see also Berg, 1992, 2004; Cruttenden, 1978; Dinnsen, Barlow, & Morrisette, 1997; Goad, 1997; Pater, 1997; Rose, 2000; Smith, 1973; Stemberger & Stoel-Gammon, 1991; Vihman, 1978; for discussion in relation to consonant harmony in adult language, see Gafos, 1999; Hansson, 2001). Whether consonant harmony in child language has origin in speech errors is a topic of ongoing debate. Vihman (1978) reports that such harmony is typically anticipatory, a directional tendency also witnessed in speech errors. Further, Stemberger and Stoel-Gammon (1991) and Bernhardt and Stemberger (1998) relate consonant harmony in child language to speech error phenomena. However, Hansson (2001) points out that consonant harmony in child language shows sensitivity to prosodic structure, which is a property he found to be lacking in his survey of adult consonant harmony. Also, Berg (2004) finds that child consonant harmony is not facilitated by phonological similarity (pace Bernhardt & Stemberger 1998).[18]

[17] Note that phonological processes do not show direct sensitivity to speech error potential in their outcomes. For example, in some cases consonant harmony or dissimilation might produce similar but different segments with increased potential for a confusion error.

[18] Bernhardt & Stemberger (1998) maintain that consonant harmony may be more likely between consonants that share certain features. Relevant, in particular, is that place harmony can be restricted to stops and nasals, while fricatives and glides may be exempt.

Further research into the comparative properties of consonant harmony in adults and in child language would surely improve our understanding of these issues.

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APPENDIX A
Stimulus materials: Critical pairs, first half of experiment

Experiment 1	*Experiment 2*	*Experiment 3*
nose tick	mode bore	meal peak
mud buff	deck numb	race moon
kneel dumb	dope note	lone nip
tack nil	nut beat	nine lap
bade mike	bus mud	tag kneel
news toot	meal dial	taught noon
tune news	mug dutch	mutt puck
pile mug	none butt	pile mole
note tore	door meal	rate math
tick nail	dine nice	pod mall
toll note	bore knoll	lip knit
mole beer	bed net	map rough
dope neck	mud buff	pole mope
pore mope	beak meat	nor lone
tease nose	dues nip	nude loot
nick tip	dear met	tore note
bore mode	nod bob	nod tease
knock daub	nice dial	knock tick
patch mass	bath mole	lit nine
knoll toad	moat bake	knife lice
numb deal	nile deed	paid main
mode bone	bite mere	load nor
bike mace	nail bill	mush rail
noon dues	bone mode	puff mutt
nice dine	note door	mob rod
knack toes	mad dice	net lose
beak meat	boot moat	mole pace
mug pit	knack bet	rear mush
pale mile	math bet	mile rice
mail pad	mere bike	moon rush
pale mitt	kneel ditch	kneel tape
tail knack	mill dull	knees tail
nail tease	bees nail	meat paid
dot knock	meat bead	mat rash
dial nice	deed mean	rock mob
bath mole	duck mug	main pace
dice nope	dip kneel	lays net
meal peak	net bell	news toot
paid main	nip dab	wrap mat
dope kneel	bake mate	tame nail
need deep	date moose	tack nod
base mate	mob doll	nip lead
mad pug	knock dot	noon tick
deer need	neck dead	till nick
duke noon	duke noon	pale meat
bike mere	neat bees	role mode

APPENDIX A (*Continued*)

Experiment 1	*Experiment 2*	*Experiment 3*
mitt pug	nope dice	nose lick
nile deck	numb dame	lack nose
batch mash	noon dues	tag knack
near tack	den mad	nick tip
till nick	deuce mood	loose nude
mate bail	dumb nile	nail tape
dumb nile	dash nope	mall pop
pit mad	dock mob	mode wrote
mash bat	budge knack	raise mate
mile pad	knoll bone	mere rob
mace bowl	mean dear	math rid
neck dice	debt neck	puff mike
pile mail	mile dime	tune news
deck numb	bum none	knack tap
mope pole	daub knock	tap knees
mike beer	beer neat	mope pore
main pace	bun knob	line knife
tone knoll	knit bail	maid pine
bade math	mike beer	knit lick
mere bath	bag knit	real map
nap tab	met dug	pug maid
tag nap	mate base	lays nap
mass pat	mash bad	mate rage
dill nip	bat mash	nap lock
nope deal	bought nod	leer niece
bus mud	moose dam	note toll
nil toes	mole buck	rhyme mice
puff mutt	bomb mike	muss patch
mutt puck	knob bit	mike peer
peer meal	mood dune	peer meal
tail near	bowl math	tease knock
meat bead	date mill	pit muss
nip ditch	boat nut	niece leap
math bowl	dine mile	wrote mere

Note: Critical pairs in second half of each experiment were composed of the same pairs but with words in each pair in the reverse order.