Nasal and Oral Consonant Similarity in Speech Errors:
Exploring Parallels with Long-distance Nasal Agreement

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Abstract

Previous research has found that ‘similar’ sounds interact in phonological long-distance nasal agreement, wherein certain oral consonants become nasals when the word contains a nasal (e.g., Kikongo: /-kun idi/ → [-kun ini] ‘planted’). Across languages, voiced stops and approximants are chiefly affected, sometimes necessarily homorganic 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 under controlled conditions with English speakers, revealed the following asymmetries in consonants’ participation in errors with nasals: (i) voiced stops > voiceless stops, (ii) homorganic voiced stops > heterorganic voiced stops, and (iii) (partially) homorganic approximants > homorganic voiceless stops. These correlate with preferentially affected consonants in long-distance nasal agreement. The data support a uniform similarity scaling for nasal-oral consonants across phonological agreement processes and speech errors. Furthermore, they are consistent with theoretical proposals that long-distance agreement has functional origins in facilitating language production.
Acknowledgements

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INTRODUCTION

The notion that similarity influences speech sounds’ potential to interact in certain phonological processes has gained attention in recent years. Phonological long-distance consonant agreement, often referred to in the literature as ‘consonant harmony’, is a relevant area. In such patterns, certain consonants within a word are obliged to match for some property. For example, in long-distance nasal agreement, certain oral consonants are produced as nasals when a nasal occurs elsewhere in the word. The Bantu language, Kikongo, offers exemplification: the suffix -idi, e.g. [-suk-idi] ‘washed’, is realized as -ini when preceded by a nasal in the stem, e.g. [-kun-ini] ‘planted’ (Rose & Walker, 2003). The agreement is long-distance in that the matching consonants may be separated by (at least) a vowel, which remains oral. Several studies have converged on the propensity of long-distance nasal agreement to affect segments that are highly similar to nasals in phonological and phonetic terms, primarily voiced stops and approximant consonants (Hansson, 2001; Rose & Walker, 2003; Walker, 2000a). Moreover, it has been demonstrated that all kinds of long-distance consonant agreement favor interactions between consonants with a high degree of similarity (Hansson, 2001; Rose & Walker, 2003). This includes agreement for such properties as laryngeal features, tongue-tip and tongue-orientation features (in coronal consonants), among others. In all cases there is action-at-a-distance in that the agreement operates across unaffected vowels and possibly other segments as well.

Taking nasal agreement phenomena as a point of departure, this paper explores whether a parallel is found in the consonants that show a tendency 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 similar consonants identified by long-distance nasal agreement are the same as those witnessed in patterns of error production.

This research question is connected to a proposal in phonological theory. Long-distance consonant agreement is suggested to have functional roots in language production, specifically, in speech planning and execution (Hansson, 2001; Rose & Walker, 2003; Walker, 2000a, 2000b). This work has identified several parallels between long-distance consonant agreement and speech errors. One shared property is the potential for action-at-a-distance. Both long-distance agreement
and speech errors may take place across intervening, unaffected segments. A second commonality involves similarity: highly similar consonants are more likely to interact in long-distance agreement and to participate in errors. It is the latter point on which the present study focuses. If long-distance nasal agreement and speech errors show a true affinity with respect to phonological similarity, then a parallel is expected in the similarity scalings evidenced by these phenomena.

This paper is organized as follows. I first exemplify attested patterns of long-distance nasal agreement and identify the similarity ranking for nasal-oral consonant pairs with which they are consistent. I then briefly discuss the theoretical background that hypothesizes a foundation for these phonological systems in facilitating speech production. This together with the identified similarity ranking 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 long-distance nasal agreement, a property which is necessary in order to test nasal-oral consonant similarity in error patterns without interference from the language’s grammar. The experiments and their results are presented in turn followed by a general discussion.

**LONG-DISTANCE CONSONANT AGREEMENT AND LINGUISTIC THEORY**

*Similarity in Long-Distance Nasal Agreement*

Cross-linguistic variation in phonological long-distance nasal agreement is illustrated by the Bantu languages, Kikongo and Ganda. Nasal agreement in Kikongo, spoken in the Democratic Republic of the Congo, produces alternations like those shown in (1) (Ao, 1991; Bentley, 1887; Dereau, 1955; Odden, 1994). In the active perfect suffix *-idi*, the voiced stop becomes a nasal stop when preceded by a nasal stop at any distance in the stem (1a). Likewise, the lateral approximant in the applicative suffix *-il* becomes a nasal under the same conditions (1b).

<table>
<thead>
<tr>
<th>Oral consonant in suffix</th>
<th>Nasal consonant in suffix</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. <em>-suk-idi</em></td>
<td><em>-niki</em></td>
</tr>
<tr>
<td>‘washed’</td>
<td>‘ground’</td>
</tr>
<tr>
<td><em>-bud-idi</em></td>
<td><em>-sim-i</em></td>
</tr>
<tr>
<td>‘hit’</td>
<td>‘prohibited’</td>
</tr>
<tr>
<td>b. <em>-sakid-ila</em></td>
<td><em>-nat-i</em></td>
</tr>
<tr>
<td>‘congratulate for’</td>
<td>‘carry for’</td>
</tr>
<tr>
<td><em>-toot-ila</em></td>
<td><em>-dumuk-is-i</em></td>
</tr>
<tr>
<td>‘harvest for’</td>
<td>‘cause to jump for’</td>
</tr>
</tbody>
</table>
The principal characteristics of Kikongo nasal agreement are as follows. Voiced stops and the approximant /l/ show agreement with a preceding nasal stop. (/l/ is the only approximant in Kikongo (Ao, 1991).) The nasal and agreeing consonant can match or differ in place of articulation. Intervening vowels and voiceless consonants do not block the process and remain unaffected. (Nasal-oral stop clusters are also neutral. See Rose and Walker (2003) for discussion and analysis of their neutrality.) A pattern similar to that of Kikongo is found in the Bantu language, Yaka, where nasal agreement applies at any distance in the stem between a nasal and following voiced stop or approximant /l, j, w/ (Hyman, 1995; Walker, 2000a). Again, the agreeing consonants may be homorganic or heterorganic.

Nasal agreement in Kikongo not only produces speech sound alternations, like those in (1), but it also enforces static patterns in the lexicon (Piggott, 1996; Rose & Walker, 2003). As a result, consonants belonging to the same morpheme regularly obey the phoneme distributions consistent with nasal agreement – phenomena of this kind are often referred to as ‘morpheme structure constraints’. There are no roots in Kikongo containing a voiced stop or approximant preceded by a nasal at any distance. Two nasals are permissible, however, as is a nasal followed by a voiceless stop.

It is observed by Rose and Walker (2003) that the sounds affected in Kikongo nasal agreement are ones which are most similar to nasals. The nature of the similarity between nasals and voiced stops and approximants is discussed presently. First, let us consider the pattern of nasal agreement in (Lu)Ganda, spoken in Uganda, which affects a more restricted set of consonants (Hansson, 2001; Katamba & Hyman, 1991).

In Ganda, nasal agreement governs possible combinations of consonants in roots. I focus here on the restrictions involving nasals and singleton oral consonants. Three series of consonants in the language are relevant: the nasals [m, n, ñ], the voiced stops, several of which alternate with non-obstruent approximants, [b/β, d/ð, j/j, ɡ], and the voiceless stops [p, t, c, k]. The generalization is that in canonical roots of the CV(C)V shape, a nasal stop and a homorganic voiced stop or its approximant alternant may not appear together (with rare exceptions). However, a pair of homorganic stops matching in nasality is acceptable, i.e. identical nasals or voiced stops/
approximants are acceptable. A nasal and heterorganic voiced consonant combination is also acceptable (subject to some limitations\(^1\)). In addition, Ganda prohibits roots in which a nasal precedes a homorganic voiceless stop, although a voiceless stop preceding a homorganic nasal is permissible. The possible and disallowed combinations of homorganic consonants are schematized in (2a), where ‘N’ signifies a nasal, ‘D’ a voiced stop or its approximant counterpart, ‘T’ a voiceless stop, and N, D and T are homorganic. Examples of acceptable forms are given in (2b) (from the Comparative Bantu On-Line Dictionary (http://cbold.ddl.ish-lyon.cnrs.fr)).

(2) **Admissible root combinations**  **Disallowed root combinations**

a. NV(V)N *NV(V)D
   DV(V)D *DV(V)N
   TV(V)N *NV(V)T

b. -mémèká ‘accuse, denounce’
   -nónà ‘fetch, go for’
   -bábülá ‘smoke over fire to make supple’
   -gùgá ‘curry favor with’
   -bónèká ‘become visible’
   -màlà ‘finish’
   -táná ‘grow septic, fester’

The Ganda patterns indicate that certain consonants occurring together in a root must agree in nasality if they are homorganic. This phenomenon has been categorized as nasal agreement operating within the morphological root (Hansson, 2001; Rose & Walker, 2003). Ganda’s hormorganicity restriction contributes to defining the classes of sounds with which nasals preferentially interact in long-distance agreement. A similar condition is also found in the Adamawa-Ubangi language, Ngbaka, in which nasal agreement operates between nasals and prenasal voiced stops only when they match in place of articulation (Mester, 1986; Rose & Walker, 2003; Thomas, 1963; Wescott, 1965).

The following statements express the cross-linguistic implications regarding consonants
that participate with nasals in nasal agreement, as exemplified by the Ganda and Kikongo patterns. These implications are also consistent with the additional cases surveyed in the typological studies of consonant agreement by Hansson (2001) and Rose and Walker (2003).

(3) Implications regarding participant sounds in long-distance nasal agreement
   a. Heterorganic $\supset$ Homorganic
   Participation of heterorganic members of a class of sounds in long-distance agreement with nasals implies participation of its homorganic members.
   Examples: Participation of heterorganic voiced stops implies participation of homorganic voiced stops, participation of heterorganic approximants implies participation of homorganic approximants.
   b. Voiceless Stops $\supset$ Voiced Stops
   Example: Participation of homorganic voiceless stops implies participation of homorganic voiced stops.
   c. Voiceless Stops $\supset$ Approximants
   Example: Participation of homorganic voiceless stops implies participation of homorganic approximants.

On the basis of these implications and the observation that nasals are prone to interact with more similar sounds in long-distance agreement, the similarity scaling statements in (4) are suggested. These statements cross two scalings of sounds according to their similarity with nasals: (i) voiced stop, approximant $>$ voiceless stop, and (ii) homorganic $>$ heterorganic.

(4) Nasal similarity scaling
   a. A nasal is more similar to a homorganic voiced stop than to a heterorganic voiced stop or a homorganic voiceless stop.
   b. A nasal is more similar to a homorganic approximant than to a heterorganic approximant or a homorganic voiceless stop.

I regard the nasal similarity scaling as situated within a larger framework of phonological similarity. First, the role of similarity in determining which sounds are affected in phonological alternations or morpheme structure constraints involving consonants at a distance is not limited to
nasal agreement alone – it has been recognized in numerous other studies in addition to the above-mentioned work on long-distance consonant agreement (Frisch, 1996; Frisch, Pierrehumbert, & Broe, in press; MacEachern, 1999; McCarthy & Prince, 1995; Padgett, 1995; Pierrehumbert, 1993; Suzuki, 1998; van de Weijer, 1994, among others). Many of these studies center on patterns in which certain speech sounds in a word must disagree with respect to some property.

Frisch et al. (in press) have proposed an objective method for computing similarity based on natural classes. Their model takes the number of shared natural classes for two segments in a given language inventory and divides it by the number of shared natural classes plus non-shared natural classes. Under this method, the exact similarity rating for a given pair of consonants varies somewhat according to the inventory shape. Nevertheless, the ordering of different pairs in the similarity ranking is generally maintained. For example, all else being equal, consonants with the same place of articulation are positioned more closely than ones with different place, and voiced stops are rated as closer to nasals than voiceless ones.

It is argued by Frisch et al. (in press) that this model is largely effective in calculating similarity between segments involved in dissimilatory phonological phenomena. In addition, Rose and Walker (2003) find it is generally suitable for identifying the classes of sounds that are favored participants in consonant agreement patterns, including nasal agreement. They note, however, that the similarity computation might be further refined by adjusting the weight that certain features carry (a possibility also mentioned by Frisch et al., in press). The natural classes similarity metric has also been successfully applied to speech error data by Frisch (1996). The comparative similarity ratings given by the natural classes metric for the interacting consonants in phonological nasal agreement and the English speech errors are summarized in *General Discussion* following the experiments below.

In addition to inventory-based observations of similarity, previous work has identified phonetic commonalities between the consonants that interact in nasal agreement (Walker, 2000a). Nasals and oral stops each involve full closure in the oral tract, and nasals and voiced stops in particular each present voicing. In homorganic nasals and oral stops, the matching site of oral tract stricture produces similar effects on the formant transitions of adjacent vowels. In the case of
nasals and approximant consonants, these share voicing, and their continuous non-turbulent airflow causes each to present weak formant structures. In addition, homorganic nasals and approximants match in the articulatory location of their constriction.

The present investigation explores whether the categories of sounds hypothesized to be most similar to nasals, as identified by the participants in long-distance nasal agreement, also show increased participation in speech errors. Before detailing the experiments, I briefly outline the theoretical background that provides foundation for the questions underlying this research.

Agreement by Correspondence in Phonological Theory

A correlation has been suggested between agreement involving highly similar consonants and the potential for action-at-a-distance. The interaction between non-adjacent consonants in long-distance nasal agreement sets it apart from local nasal harmony. In the latter processes, a [Nasal] feature is extended from a nasal stop or nasal vowel through a continuous sequence of segments, including vowels (Walker, 2000c). However, this procedure is not applicable to long-distance nasal agreement, where intervening oral vowels and voiceless consonants signal a lack of continuous nasalization carrying between agreeing segments.

For long-distance consonant agreement, Rose and Walker (2003) have argued that a different mechanism is at work. They posit that the occurrence of relatively high similarity between consonants stimulates a relation to be constructed between them, formally instantiated in terms of a correspondence relation in phonological theory (building on Walker, 2000a, 2000b; see Hansson, 2001 for a related proposal; on Correspondence Theory, see McCarthy & Prince, 1995). The relation’s functional origins are hypothesized to lie in the area of planning and execution of speech. Psycholinguistic studies in association with spreading-activation models have found evidence that speakers and listeners form connections in an utterance between speech sounds that they recognize as similar (e.g. Dell, 1984, 1986; Dell & Reich, 1980; MacKay, 1970, 1987; McClelland & Rumelhart, 1981; Stemberger, 1982, 1985a, 1985b). Furthermore, in order for sounds to show an interaction in phonological encoding phenomena, such as speech errors, they need not be contiguous, for example, they often belong to the onsets of separate syllables.
Under Rose and Walker’s proposal, the established relation between similar segments mediates long-distance agreement, a model they term ‘agreement by correspondence’. Identity constraints, which require identical feature specifications in related segments, enforce matching for individual properties, such as nasality, as depicted in Figure 1. Coindexing in this figure signifies the existence of a correspondence relation. For purposes of illustration, the consonants under attention are annotated as [Nasal] or [Oral], but this does not make any claims about the particular representation of nasality features.

(Long-distance nasal agreement, posited to arise through agreement by correspondence, shows different properties from local nasal harmony, which is believed to come about via feature spreading (or gesture extension) between adjacent segments. These differences correlate with the typology of correspondence-based phenomena versus spreading processes in general. The first difference is the potential for distance interaction. Long-distance nasal agreement may occur between consonants belonging to separate syllables, with at least a vowel intervening, while local nasal harmony does not skip segments. Second, the set of participating segments are different. Long-distance nasal agreement operates between segments that are similar to nasals, primarily voiced stops and approximants, and sometimes only those that are homorganic. On the other hand, vowels are the most likely segments to be affected by local nasal harmony, and obstruents, including voiced stops, are the least likely to participate in such processes. For example, in the Austronesian language, Sundanese, nasalization spreads progressively through sequences of adjacent vowels and laryngeals, as in (5a), but it is blocked by non-laryngeal consonants, as in (5b) (Cohn, 1990).

(5)  **Sundanese**

<table>
<thead>
<tr>
<th></th>
<th>Sundanese</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>jātān</td>
<td>‘to wet’</td>
</tr>
<tr>
<td></td>
<td>kumāhā</td>
<td>‘how?’</td>
</tr>
<tr>
<td>b.</td>
<td>nūdag</td>
<td>‘to pursue’</td>
</tr>
<tr>
<td></td>
<td>mōloho</td>
<td>‘to stare’</td>
</tr>
</tbody>
</table>

A cross-linguistic study of local nasal harmony has revealed that an implicational hierarchy governs the participant segments in these processes (Walker, 2000c). Sounds are scaled according
to their compatibility with superimposed nasalization, where those that are most compatible, namely vowels, are most likely to undergo nasal harmony. Obstruents are least compatible with nasalization (while maintaining their obstruency), and are thus the least likely participants.

A final difference concerns blocking. Nasal agreement that operates at a distance does not show blocking effects, that is, intervening non-participant segments, such as vowels and voiceless consonants, do not obstruct agreement. In contrast, segments that do not participate in local nasal harmony generally block it, as in Sundanese. The differences are summarized in (6).

(6) Long-distance agreement Local harmony

Locality Includes action-at-a-distance. Affects only adjacent sequences.
Participants Similar segments. Segments compatible with nasalization.
Blocking No. Yes, incompatible segments block.

As Rose and Walker (2003) discuss, these differences between local harmonies and long-distance agreement follow from their separate modeling. Local harmony affects only adjacent segments because it involves local spreading of a continuous feature. However, since long-distance agreement arises through feature matching in correspondent segments, it is not restricted to adjacent sounds. In long-distance agreement, participant segments are similar, because it is similarity that causes a correspondence relation to be established between them. On the other hand, spreading simply extends a feature as far as possible until encountering a segment with which it is insufficiently compatible. Intervention of an incompatible segment blocks the spreading process. In agreement by correspondence, the identity of related segments is checked – a single feature is not extended across intervening segments, so no blocking is expected.

Returning to the hypothesized foundation of agreement by correspondence in psycholinguistic considerations, an analogue is observed in the activity of similarity in language production. It has been well-established that the likelihood of two phonemes participating in a speech error increases with their similarity (Frisch, 1996; Fromkin, 1971; Garrett, 1975; Kupin, 1982; Levitt & Healy, 1985; MacKay, 1970; Meyer, 1992; Nootbooom, 1967; Shattuck-Hufnagel & Klatt, 1979; Stemberger, 1982; Vousden, Brown, & Harley, 2000). Hence, both long-distance consonant agreement and speech errors show an increased potential for interaction between similar
speech sounds. Focusing on nasal agreement, this provokes the question: is there a parallel between the consonants that are affected in long-distance nasal agreement and those that have an increased likelihood to participate with nasals in speech errors? In order to determine the sounds that are prone to participate with nasals in speech errors, it is necessary to examine a language that does not have nasal agreement operating as a fixed generalization in its grammar. The investigation undertaken in this research consists of series of experiments that examine errors produced by speakers of English, using the SLIPS technique of error elicitation (Baars & Motley, 1974; Baars, Motley, & MacKay, 1975; Motley & Baars, 1975). These experiments are directed at exploring whether the sounds that pattern as similar to nasals in speech error phenomena match those affected in nasal agreement; an overview of the experiments is given in the following section.

The results will be brought to bear on the foundation for grammaticalized patterns of long-distance nasal agreement. As mentioned earlier, it has been suggested that phonological agreement at a distance has grounding in the phonological encoding and execution of speech. The occurrence of sounds in an utterance that are similar but different are observed to pose difficulties in language production. By enforcing a distribution in which similar speech sounds must be identical for some property, it is proposed that consonant agreement has the effect of eliminating certain sound combinations that have a relatively high probability of interference in (i) the speech plan, which organizes and sequences phonological units, and (ii) the coordination of the motor controls that execute the plan. If the experiments reveal that the same similarity is operative in speech error patterns as in long-distance nasal agreement, the results would be consistent with the proposal that phonological processes of long-distance consonant agreement have functional roots in facilitating ease of speech production. These issues are addressed in the general discussion following the experiments.

OVERVIEW OF EXPERIMENTS

The theoretical issues discussed above give rise to the general hypothesis in (7), which guides the experiments conducted in this study.
(7) **Hypothesis**

The consonants that are most similar to nasals according to the scaling suggested by patterns of long-distance nasal agreement will show higher participation in speech errors with nasals in languages that do not have nasal agreement.

The language investigated here is English, and the experiments investigate errors involving nasals with oral stops and liquids. The inventory of stops and liquids in English is shown in Figure 2 alongside their plain (non-geminate) counterparts in Kikongo and Ganda, the languages for which nasal agreement was exemplified earlier. The experiments examine bilabial and coronal consonants only. These sounds, boxed in Figure 2, are comparable across the three inventories for stops in the places of articulation examined (though Ganda is noted to show approximant alternants for its voiced stops). In regard to liquids, each language presents a coronal lateral (in Ganda the lateral and coronal voiced stop are not contrastive). English also has the liquid /r/.

(INSERT FIGURE 2 ABOUT HERE)

A series of experiments were conducted to test the three specific sub-hypotheses in (8) stemming from the general hypothesis in (7).

(8) **Sub-hypotheses tested by experiments**

a. **Experiment 1: Voicing**

H1: There will be more errors involving nasal and voiced stops and than nasals and voiceless stops.

b. **Experiment 2: Place**

H2: There will be more errors involving nasals and homorganic voiced stops than nasals and heterorganic voiced stops.

c. **Experiment 3: Manner (property weighting)**

H3: There will be more errors involving nasals and (partially) homorganic approximants than nasals and homorganic voiceless stops.

Building on the observation that higher similarity correlates with more errors, each of these experiments tests an aspect of the similarity scaling in (4). Experiment 1 focuses on the ranking of nasals and voiced stops as more similar than nasals and voiceless stops. This links with the
Kikongo-type of nasal agreement, in which voiced stops participate but not voiceless stops. Moreover, in Ganda, voiced stops are affected in more contexts than voiceless ones. Experiment 2 centers on the contribution of identical place to similarity. This issue arises from the Ganda-type pattern, in which homorganic consonants participate to the exclusion of heterorganic ones. Finally, Experiment 3 addresses a question of property weighting, specifically comparing the relative similarity of nasals and approximants versus nasals and voiceless stops. The Kikongo pattern revealed that approximants may participate in nasal agreement to the exclusion of voiceless stops, and in Ganda, approximant alternants are affected in more contexts than voiceless stops.

Nasals and approximants are sonorant sounds, which Ladefoged (1997:615) characterizes as sharing the acoustic property of having a “periodic, well-defined, formant structure.” Nasals and approximants are also both voiced. They differ, however, in stricture. Nasals are produced with complete oral occlusion, while approximants present continuous non-turbulent oral airflow. In addition, [l], in particular, differs from nasals in being a lateral sound. Nasals and voiceless stops, on the other hand, match in stricture, both having full stoppage in the oral cavity. But nasals are sonorants, while voiceless stops are obstruents, and they differ in voicing. Experiment 3 investigates the weight the different shared properties carry. Studies bearing on phonological similarity have found that it is not determined by a simple comparison of sums of shared features, but rather features may make a different degree of contribution, whether this is accomplished by the natural classes metric and/or individual feature weighting (e.g. Frisch et al., in press; Rose & Walker, 2003). Experiment 3 uses error-based evidence to examine whether nasals show more similarity with sonorants, despite different stricture and possible further differences such as laterality, than they show with voiceless stops, which match in stricture but disagree in obstruency and voicing.

**EXPERIMENT 1: VOICING**

Experiment 1 investigated the hypothesis that there will be more errors involving nasals and voiced stops than nasals and voiceless stops. Experiment 1 also asked three sub-questions: (i) does place of articulation in homorganic consonants affect the error rate? (ii) does the order of nasal-
oral consonants affect the error rate? and (iii) does the earliness of production of a word pair in the experiment affect the error rate? In its principal investigation, Experiment 1 partially replicated an experiment by Stemberger (1991b) which investigated whether more errors occur involving nasals and voiced obstruents (examining both stops and fricatives) than nasals and voiceless obstruents.

Like the hypothesis that this experiment investigated, sub-questions (i) and (ii) probed possible points of intersection between speech error patterns and long-distance nasal agreement. Apart from homorganicity conditions, phonological nasal agreement does not show restrictions for place of articulation. For example, in languages with bilabial and alveolar nasals and oral stops, agreement is not limited to one place only. Sub-question (i) investigated whether speech errors involving nasals and oral stops are evenly distributed across bilabials and alveolars. Some patterns of nasal agreement show a directionality effect such that only oral consonants that follow a nasal in the word are affected (Rose & Walker, 2003; Walker, 2000a). Sub-question (ii) examined whether a parallel directionality tendency is observed in speech errors. The third sub-question relates to a methodological issue. It investigated whether more errors are generated early or late in the experiment. This bears on whether subjects get better at the production task over time, or whether they produce more errors later, possibly due to lack of concentration or fatigue.

**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 et al., 1975; Motley & Baars, 1975; applications include Dell, 1984, 1990; Stemberger, 1991a, 1991b; Stemberger & Treiman, 1986). Subjects are shown monosyllabic word pairs one at a time on a video screen for silent reading. Some word pairs are followed by a cue for the subject to say 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 rhyme with the words in the critical pair, but have different initial consonants. In the second and third priming pairs, the initial consonant-vowel sequences (but not
the final consonant) matched those of the words in the critical pair, but in the opposite order. Table 1 shows a sample priming structure.

**Method**

**Materials.** The stimuli were 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 under an exchange, anticipation or perservation error with the initial consonants. The composition of the critical pairs was controlled for the five factors listed in (9), fully crossed.

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

i. Voicing: initial nasal and voiced stop word pairs vs. initial nasal and voiceless stop.

ii. Place: bilabial vs. alveolar initial consonants within a word pair.

iii. Order: nasal-initial word first vs. oral stop-initial word first.

iv. Earliness: word pair cued in first half of the experiment or the second half.

v. Vowel: same vs. different vowels within words in a pair.

The first factor is related to the hypothesis that Experiment 1 investigated. Factors (ii-iv) are correlated with subquestions (i-iii), respectively. Place of articulation for the consonants under study was restricted to bilabial and alveolar because the velar nasal does not occur in word-initial position in English. Factor (v) controls for what is known as 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, 1970; Nooteboom, 1967; Wickelgren, 1969). For example, the repeated /i/ in the initial syllables of the words *weekly reading* could encourage a slip such as *reekly weeding*. Since long-distance nasal agreement patterns operate
regardless of whether the neighboring vowels match or are different, the word list was balanced to
contain equal numbers of word pairs with a repeated vowel and ones containing different vowels.

Among the words appearing in critical pairs, all words within a place of articulation, i.e. those
with an initial bilabial [p, b, m] or an initial alveolar [t, d, n], had relatively equal mean
frequency and similar standard deviations. In addition, words within a critical pair were balanced
for lexical frequency. Two databases were used to compute mean frequency: word frequencies
were drawn from Carroll, Davies, and Richman (1971) and Zeno (1995).

In addition to critical pairs and primers, the word list included 500 filler pairs, 200 of which
were cued for the subject to say aloud. Cued filler pairs were preceded by between zero and three
uncued filler pairs, which were not organized around a phonological priming structure. The order
of critical pairs (each together with their preceding priming pairs) within the list was randomized;
however, sequences of critical 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 primers) and the number of uncued fillers that
preceded each cued filler were randomized. Adjacent pairs that contained the same word were
prevented. To control for within-list frequency, each word appeared in the list exactly six times.
Word pairs that formed special phrases, e.g. ‘love sick’, were excluded, as were pairs containing
rhyming words. The list was split into two equal halves, part A and part B, equally balanced for the
factors listed in (9).

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 center of the screen for 900 ms
followed by 100 ms of blank screen. 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 sec and for a cued pair was 2.45 sec. All subjects were exposed to the same word list,
although alternating subjects were given part A or part B of the word list first. 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 between parts A and B. Responses were audio-recorded for later analysis and were coded during the course of the experiment by an investigator using a button box.

The error coding procedure was as follows. Each subject’s production of a critical pair was assigned a code: correct production, assigned in cases of no audible error, initial consonant error, assigned in cases 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. Button box coding was verified after the experiment by listening to the audio recording of responses. Any cases of disagreement were resolved by two investigators listening to the pairs again. The investigator listening to the audio tape transcribed and classified initial consonant errors according to the categories listed in Table 2.

(The insert table 2 about here)

Some remarks on classifications are in order. False start errors were coded separately from exchanges and anticipations, because they were ambiguous between these error types. As a consequence of the SLIPS stimuli construction, the majority of errors were exchanges. 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 organization 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, wherein the nasal feature (or lowered velum gesture) intrudes on the initial consonant in the first word (e.g. Browman & Goldstein, 1990). Similarly in the word exchange example, the 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 has the potential to contribute to the error rate, and they were thus included in the error tally.

Productions categorized as other were those that were produced incorrectly but not involving the initial consonants. Examples of this type include errors limited to the vowels or coda consonants, e.g. noon duke \(\rightarrow\) noon duck, beak meat \(\rightarrow\) beak meek. Also included here were cases
of apparent memory errors, where the subject said nothing when cued or remembered only the first word of the pair. A third kind of error coded as other were occasions where subjects said aloud a priming pair when cued instead of the critical pair. Productions categorized as other were not included in the error counts for statistical analysis.

**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.

**Results and Discussion**

There were 159 initial consonant errors, yielding an error rate of 2.83% (the proportion of critical pair trials in which an error occurred). There were 95 errors in critical pairs containing an initial nasal and initial voiced stop (either order) versus only 64 errors in critical pairs containing an initial nasal and initial voiceless stop (either order). This difference is significant, $\chi^2(1) = 6.044, p = .0139$, confirming the principal hypothesis examined in this experiment. In Table 3, the data are broken down by voicing and place of articulation.

The findings in regard to the sub-questions were as follows. Place of articulation in homorganic initial consonants did not have a significant effect on the error rate, $\chi^2(1) = .308, ns$. The order of nasal-oral phonemes was also not significant, $\chi^2(1) = .006, ns$, nor was the earliness factor, $\chi^2(1) = .308, ns$. The errors reported as a function of these factors are given in Table 4.

Possible interactions of these factors with voicing were examined. The interaction of voicing and place of articulation was not significant, $\chi^2(1) = .265, ns$, nor was voicing and order, $\chi^2(1) = .151, ns$. Although the proportion of errors involving nasals and voiced stops vs. nasals and voiceless stops was observed to be greater in the first half of the experiment than in the second, the interaction of earliness and voicing misses significance, $\chi^2(1) = 3.066, p = .080$.

In summary, the findings of Experiment 1 were that the voicing factor is significant: more errors occurred involving nasals and voiced stops than nasals and voiceless stops. Discussion in
Let us consider the relation of the results of this experiment to those of Stemberger (1991b). First, the effect of the voicing factor found in this study is consistent with Stemberger’s finding that there were more errors generated between nasals and voiced obstruents than nasals and voiceless obstruents in a SLIPS study with speakers of English. Stemberger found that this holds true of both nasal-stop pairs and nasal-fricative pairs. Although he examined consonant pairs at both labial and alveolar places of articulation, he did not compare the effects for place within that experiment. However, in an error corpus study and another SLIPS experiment, Stemberger found that pairs of labial consonants participated in more errors than alveolar pairs. However, the differences according to place of articulation were not found for certain kinds of consonant pairs. Specifically, no significant difference was found in oral stop-nasal pairs and voiced stop-voiceless stop pairs, but all pairings involving fricatives showed an effect for place. The lack of an effect of place in oral stop-nasal pairs in the present experiment thus accords with Stemberger’s findings. He speculates that differences in place only produce a significant effect in the fricative pairings, because errors involving them are less frequent, and factors influencing error rates are most prominent in less frequent error types.

**EXPERIMENT 2: PLACE OF ARTICULATION**

Experiment 2 investigated the hypothesis that there will be more errors involving nasals and homorganic voiced stops than nasals and heterorganic voiced stops. It also asked three sub-questions: (i) does nasal place of articulation affect the error rate? (ii) does the order of nasal-oral consonants affect the error rate? and (iii) does the earliness of production of a word pair in the experiment affect the error rate? Once again, the hypothesis and sub-questions (i) and (ii) center on possible correlations with patterns of long-distance nasal agreement.

**Method**

*Materials.* The stimuli were designed in much the same way as for Experiment 1. The composition of critical pairs was controlled for the five factors in (10), fully crossed.
Experiment 2: Controlled factors in critical pairs

i. Place: initial nasal and homorganic voiced stop word pairs vs. initial nasal and heterorganic voiced stop.

ii. Nasal place: bilabial vs. alveolar nasal.

iii. Order: nasal-initial word first vs. oral stop-initial word first.

iv. Earliness: word pair cued in first half of the experiment or the second half.

v. Vowel: same vs. different vowels within words in a pair.

The places of articulation investigated were again bilabial and alveolar. Thus the pairs under comparison were initial [m]-[b] versus [m]-[d] and initial [n]-[d] versus [n]-[b]. The word list contained equal numbers of word pairs with repeated vowels and non-repeated vowels, balanced across the four other factors. The word list contained only real words of English, and words in critical pairs became real words under an exchange, anticipation or perseveration error involving the initial consonants. Frequency was controlled for in the same way as in Experiment 1 for words within a critical pair and within groups of words belonging to critical pairs for each nasal place of articulation, i.e. [m, b, d] and [n, d, b]. The phonological priming structure and inclusion of filler pairs followed the same scheme as before. An example priming sequence for the critical pair duck mug, which has matching vowels, is luck thug, mutt dull, mud dumb.

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

Subjects. Subjects were 37 undergraduates at the University of Southern California who were native speakers of English. There were 32 subjects enrolled in psychology courses, who received course credit for participation, and 5 others, who received monetary compensation.

Results and Discussion

There were 132 initial consonant errors, for an error rate of 2.2%. There were 91 errors in critical pairs containing an initial nasal and initial homorganic voiced stop (either order) and only 41 errors in pairs with an initial nasal and initial heterorganic voiced stop (either order). This asymmetry is significant, $\chi^2(1) = 18.939$, $p < .0001$, and it confirms the experiment’s principal hypothesis: more errors occurred involving nasals and homorganic voiced stops than nasals and heterorganic ones.
Table 5 shows the data broken down by homorganic/heterorganic place and nasal place.

(INSERT TABLE 5 ABOUT HERE)

Turning to the sub-questions, nasal place was not a significant factor, $\chi^2(1) = .273$, ns, nor was the order factor, $\chi^2(1) = .030$, ns. However, the earliness factor was significant, $\chi^2(1) = 16.030$, $p < .0001$: there were 89 errors in the first half of the experiment and just 43 in the second half. This suggests that subjects improved at the task over time. The errors reported according to the factors of nasal place, order, and earliness are presented in Table 6. There was no significant interaction between the place factor and nasal place, $\chi^2(1) = .026$, ns, nasal-oral consonant order, $\chi^2(1) = .2$, ns, or earliness of error production, $\chi^2(1) = .296$, ns.

(INSERT TABLE 6 ABOUT HERE)

To summarize, the findings of Experiment 2 are that same place of articulation significantly increases the likelihood of an initial consonant error involving nasals and voiced stops. Furthermore, production of a critical pair in the first half of the experiment increases the likelihood of an initial consonant error.

**EXPERIMENT 3:**
**MANNER: PROPERTY WEIGHTING**

Experiment 3 investigated the hypothesis that there will be more errors involving nasals and (partially) homorganic approximants than nasals and homorganic voiceless stops. It also asked three sub-questions: (i) does nasal place of articulation affect the error rate? (ii) does the order of nasal-oral consonants affect the error rate? and (iii) does the earliness of production of a word pair in the experiment affect the error rate?

**Method**

**Materials.** The stimuli were designed along the same lines as the first two experiments. The critical pairs in Experiment 3 were controlled for the five factors in (11), fully crossed.

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

i. Manner: initial nasal and (partially) homorganic liquid word pairs vs. initial nasal and homorganic voiceless stop.
ii. Nasal place: bilabial vs. alveolar nasal.

iii. Order: nasal-initial word first vs. oral consonant-initial word first.

iv. Earliness: word pair cued in first half of the experiment or the second half.

v. Vowel: same vs. different vowels within words in a pair.

As in the previous experiments, the nasals’ place of articulation were bilabial or alveolar. Errors were compared involving [n] and [t] versus [n] and [l] (alveolar for some speakers, dental for others). Also compared were errors involving [m] and [p] versus [m] and [r]. Although [r] is produced with approximation in the alveolar region, it also involves a labial articulation for many English speakers in the form of lip rounding (Ladefoged 1993:65). Due to its labialization, [r] is the closest liquid of English in terms of place for the labial nasal [m]. The liquid [r] was chosen to test against [m] instead of the labio-velar glide [w] in order to maintain closer uniformity with the liquid [l] paired with [n]. The focus of this experiment was to test whether there are more errors involving nasals and liquids than nasals and voiceless stops. Experiment 2 determined that there are more errors between nasals and consonants that match in place of articulation. Thus, if the 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.

As before, all critical pairs consisted of real words of English and became real words of English under an initial consonant exchange error, anticipation or perseveration. There were equal numbers of word pairs containing repeated vowel phonemes as ones containing different vowels. Frequency was controlled as in the first two experiments within word pairs and within the critical pair words for the group with initial [m, r, p] and the group with initial [n, l, t]. The priming structure and interspersion of filler pairs, some of which were cued, also followed Experiments 1 and 2. An example priming sequence for the critical pair *nine lap* is *fine sap, latch nice, lack nile*.

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

*Subjects.* Subjects were 35 undergraduates at the University of Southern California who were native speakers of English. There were 24 subjects enrolled in psychology courses, who
received course credit for participation, and 11 others, who received monetary compensation.

Results and Discussion

There were 157 initial consonant errors, yielding an error rate of 2.8%. There were 103 errors involving initial nasals and (partially) homorganic liquids (either order) versus 54 errors involving initial nasals and homorganic voiceless stops (either order). This difference is significant, $\chi^2(1) = 15.293$, $p < .0001$, confirming the hypothesis that nasals participate in more errors with liquids than voiceless stops. The results are reported in Table 7, as a function of oral consonant manner and nasal place. Previous studies have noted that stricture and voicing features are among the ones most often shared by consonants that participate together in a speech error (e.g. MacKay, 1970; Shattuck-Hufnagel & Klatt, 1979). The results of this experiment add further delineation, suggesting that nasals and approximants, which are both voiced sonorants, are more prone to interact than nasal and voiceless stops, despite the latter pair's identical stricture.

(INSERT TABLE 7 ABOUT HERE)

On the sub-questions, for which the data are in Table 8, it was once again found that nasal place was not a significant factor in the error pattern, $\chi^2(1) = .057$, ns, nor was the order factor, $\chi^2(1) = 1.433$, ns. On the other hand, as in Experiment 2, there were significantly more errors in the first half of the experiment: 94 errors occurred in the first half and only 63 in the second half, $\chi^2(1) = 6.121$, $p = .014$. There was no significant interaction between the manner factor and nasal place, $\chi^2(1) = .26$, ns. The greater number of errors thus held for both nasal-liquid pairings, and despite the partial place match for [m]-[r], the number of errors involving these consonants still outweighed the fully homorganic [m]-[p] pairs. No significant interaction was found between manner and earliness of error production, $\chi^2(1) = .013$, ns. However, there was an interaction between manner and nasal-oral phoneme order, $\chi^2(1) = 6.274$, $p = .012$. More errors occurred in pairs containing nasals and voiceless stops if the first consonant was nasal (37 errors) than the reverse (17 errors). For liquids, the error count under both orders was relatively close: 54 errors in pairs with the liquid first and 49 with the nasal first. This was the only experiment for which an interaction involving nasal-oral phoneme order was found. The reason for the occurrence of an
effect with only the voiceless stops here, and here only, is not immediately clear.

(INSET TABLE 8 ABOUT HERE)

To summarize, the findings of Experiment 3 are that nasals participate in more initial consonant errors with (partially) homorganic liquids than voiceless stops. In addition, there were more initial consonant errors in the first half of the experiment, and the likelihood of an error between a nasal and voiceless stop increased if the nasal-initial word was first in the critical pair.

GENERAL DISCUSSION

General Hypothesis and Similarity Scaling

This series of experiments examined whether the phonological similarity scaling suggested by cross-linguistic patterns of long-distance nasal agreement is also supported by language performance data. It was hypothesized that there would be a parallel between the sounds that participate in more speech errors involving nasals and the consonants that show a higher tendency to participate in long-distance nasal agreement. This hypothesis was borne out with respect to each of the factors examined. Assuming that greater similarity increases the likelihood that phonological units will interact (e.g. Frisch, 1996; Fromkin, 1971; Hansson, 2001; MacKay, 1970; Rose & Walker, 2003; among others), this study finds support for a convergence in sound similarity across the areas of language performance and phonology. In particular, the oral consonants identified as similar to nasals according to the speech production phenomena examined in these experiments line up with those identified as similar in nasal agreement, as scaled in (4).

Before proceeding to the experiments’ sub-questions, I discuss some further issues bearing on the interpretation of this primary result. First, this research examined errors induced in an experimental setting. Stemberger (1992) discusses the comparability of experimentally elicited speech errors with naturalistic data, finding that they show a great deal of convergence. He argues that “experimental error-induction techniques constitute a reasonable facsimile of normal language processing” (1992:211), and they have the advantage of reducing the interference of perceptual bias. Nevertheless, Meyer (1992:197) suggests that error data generated in an experimental setting should be validated by comparison to errors observed in naturally occurring speech. While a
comprehensive comparative investigation is beyond the scope of this study, counts from the MIT corpus of spontaneous speech errors reported in Shattuck Hufnagel and Klatt (1979:43) were examined for the relevant consonant pairs.

The spontaneous errors in question consist of 1620 consonant substitutions and exchanges. The error counts from that corpus for the consonant pairs examined in this study are given in Table 9. There were 39 errors involving nasals and voiced stops, but just 20 involving nasals and voiceless stops, $\chi^2(1) = 6.119, p = .0134$. The 39 errors involving nasals and homorganic voiced stops exceeded the 10 involving nasals and heterorganic voiced stops, $\chi^2(1) = 17.163, p > .0001$, and the 61 errors involving nasals and (partially) homorganic liquids outstripped the 20 involving nasals and homorganic voiceless stops, $\chi^2(1) = 20.753, p > .00001$. These data show the same trends as the experimental findings. This suggests that the consonant pairs which present a higher level of interaction in errors elicited by the SLIPS procedure are not limited to an experimental setting but show a corresponding increased interaction in naturalistic errors as well.

As discussed above, the consonants that participated in more speech errors in the experiments are interpreted as more similar than those that participated less. Nevertheless, given that phoneme frequency can impact the occurrence of errors (e.g. Dell, 1986; Levitt & Healy, 1985; Stemberger, 1991a, 1991b), it was necessary to examine its possible role in the results. A post hoc examination of the data considered two possible effects of phoneme frequency. First, there should be more errors involving phonemes of lower frequency, and second, there should be a greater error rate among bilabials than alveolars, because bilabials are less frequent (Stemberger, 1991a:167, 1991b:97). The error rate by consonant for each experiment is given in Table 10 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.

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The voiceless stops [p] and [t] have a greater mean frequency than [b] and [d], respectively. However, in Experiment 1 the voiceless stops had lower error rates than the voiced stops. In addition, there were more errors involving alveolars than bilabials, although the difference was not
significant. These error patterns thus were not determined by phoneme frequency.

Experiment 2 compared nasal and oral consonant pairs with same versus different place of articulation. The data for this experiment are broken down in Table 10 according to the voiced stop’s paired nasal. The mean phoneme frequency for voiced oral stops predicts a higher error rate for pairs involving /b/ vs. /d/ (with control for paired nasal). When paired with [m], the errors involving [b] exceeded that of [d], but the reverse was observed in pairings with [n]. The observed error rates were thus not uniformly consistent with a phoneme frequency effect but instead regularly correlate with a pattern in which there were more errors in pairs of homorganic nasals and voiced stops than in corresponding heterorganic pairs. Furthermore, although the mean error rate for pairs containing two bilabial consonants was 3.2% versus 2.9% for pairs containing two alveolars, the difference was not significant ($\chi^2(1) = .60$, ns).

For Experiment 3, mean phoneme frequencies predict more errors involving [p] than involving [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]. In addition, there was no significant difference in the error rate according to place of articulation; the error counts of 77 in pairs with [m] and 80 in pairs with [n] were remarkably close. Again, the error pattern does not regularly conform with that predicted by a phoneme frequency effect.\(^7\)

Another issue to consider, bearing on the role of similarity, concerns the ambiguity of the level of phonological structure at which the 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. However, if they involved gestural exchanges, then an error that re-ordered two gestures could conceivably incur a greater cost than one re-ordering only a single gesture, which might affect the error pattern. Many studies have argued that the units involved in phonological errors are most commonly segments (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 in nature, is more prevalent than previously understood (Frisch & Wright, 2002; Mowrey & MacKay, 1990; Pouplier, 2003; Pouplier, Chen, Goldstein, & Byrd, 1999).
The present study measured only errors that produced audibly perceptible results. Hence, gradient errors of the kind in which inaudible traces or intrusions of motor activity occurred were 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 of the errors involving initial consonants were an exchange or substitution affecting all properties. Thus, there were vanishingly few errors in which, for example, the initial consonant pair [p]-[m] was erroneously produced as [b]-[m], substituting only voicing. This is in agreement with the finding of previous studies that (non-gradient, audible) feature errors are rare. This suggests that the error patterns found in this research were not determined by differences in the number of units undergoing movement.

Further support for this conclusion comes from the results of Experiment 3. Nasals and liquids differed by more articulatory properties than nasals and voiceless stops, but they nevertheless showed a greater interaction. The consonants [m]-[r] differ in nasality, stricture, coronality, and (for some speakers) retroflexion, and the pair [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 involving nasals and voiceless stops.

In most cases, segments that are more similar also match in more gestures. However, as mentioned earlier, studies on phonological similarity have found that the computation of relative similarity is somewhat more complex. An objective similarity calculation below lends further support to the conclusion that similarity chiefly determines the error patterns found in this study.

**Sub-questions**

Next I consider the results of the set of subquestions that this research investigated. The first sub-question centered on the factor of place of articulation. The experiments found that place of articulation of initial homorganic stops or nasals in word pairs did not have a significant effect on the speech error rate. The lack of effect of place shows a correlation with patterns of long-distance nasal agreement. I am not aware of any case of long distance nasal agreement that is restricted to
nasal-oral stop pairs in a proper subset of the available places of articulation. This is consistent with the hypothesized functional basis for long-distance nasal agreement noted earlier. Since bilabial and alveolar nasals (and bilabial and alveolar homorganic nasal-oral stop pairs) did not significantly differ in their participation in speech errors, neither place appears to present a greater difficulty in phonological encoding or execution. Hence, neither is singled out for exclusive participation in phonological nasal agreement.

The second sub-question focused on the order of initial nasal-oral consonants in word pairs. In Experiment 3 there were more errors involving nasals and voiceless stops when the nasal appeared first in the critical pair than under the reverse order. This shows a correlation with the ordering restriction in Ganda, in which TV(V)N roots are acceptable, but NV(V)T roots are avoided. However, in Experiment 1 the ordering factor did not produce an effect in nasal-voiceless stop pairs, for reasons that are not clear. Indeed, ordering differences did not have a significant effect on the error rate with any nasal-oral consonant pairs beyond that noted in Experiment 3. In this respect, the error patterns do not show an across-the-board match with nasal agreement processes. In cases where directionality is apparent, nasal agreement shows a tendency for progressive agreement, i.e. agreement operates between nasals and oral consonants that follow them in the word but not preceding oral consonants. This is witnessed not only in agreement with voiceless stops in Ganda but also with voiced stops and approximants in Kikongo. The only partial correlation between speech error patterns and long-distance agreement might indicate that directionality conditions in nasal agreement are not singularly grounded in production planning (but see discussion of directionality in long-distance consonant agreement in general, below). Alternatively, the SLIPS technique might not be the optimal paradigm to test effects of phoneme order in errors.

The third sub-question asked whether the earliness of production of a critical pair in the experiment had an effect on the error rate. In Experiments 2 and 3, there were significantly more initial consonant errors in the first half of the experiment than in the second half. This suggests that subjects got better at producing critical pairs over time. It is conceivable that the improvement arose because subjects gradually noticed that a priming pattern existed for some pairs, which raised
their attention that a cued form might be coming. It is not clear why the same improvement pattern was not found with significance in Experiment 1. However, Experiment 1 showed a kind of shift in the second half. The gap between the number of errors involving nasal and voiced stops versus nasals and voiceless stops was greater in the first half of the experiment than in the second half, although this difference only approached significance. It is possible that in Experiment 1 subjects tended to adopt a strategy in the second half of the experiment which improved their performance in the pairs that presented the most difficulty. This could have caused the contrast witnessed in the first half of the experiment to weaken in the second half. The improvements observed in the second part of the experiments bear on a methodological point: they suggest that a shorter experiment performed with more subjects would elicit more errors, and possibly sharper contrasts in error patterns. Alternatively, an experiment of the present length might elicit more errors if fillers were constructed to include sequences closely resembling critical pair primes, but without a following cued pair, or with a following cued pair that did not contain the phoneme reversal structure used in critical pairs.

Theoretical Implications

Calculating Similarity. Returning to the principal issue under investigation, this research has found that sounds which are more likely to participate in errors with nasals correspond with those that are more likely to be affected in long-distance nasal agreement. This is suggestive of a parallel in sound similarity across these phenomena and supports the general applicability of the phonological similarity scaling statements given in (4).

As mentioned earlier, the natural classes similarity metric proposed by Frisch et al. (in press) has proven generally effective in predicting observed phoneme similarities across such phenomena as speech errors, long-distance consonant agreement and dissimilatory restrictions. The relative similarities identified in this study are thus usefully compared with the results of the objective similarity computation.

The speech error results are considered first, using the model of Frisch et al. (in press) in (12). Completely identical segments are given a rating of 1.
(12) \[ \text{Similarity} = \frac{\text{Shared natural classes}}{\text{Shared natural classes} + \text{Non-shared natural classes}} \]

The similarity values have been calculated for English by Frisch (1996:40). Experiment 1 found more errors involving homorganic nasal-voiced stop pairs than homorganic nasal-voiceless stop pairs. Consistent with the experimental results, the similarity rating for nasals paired with homorganic voiced stops, averaged across places of articulation, is .37, while the rating for nasals paired with voiceless stops is just .18. In Experiment 2 there were more errors involving nasals and homorganic voiced stops than nasals and heterorganic voiced stops. This correlates with the averaged similarity calculations of .37 for nasals and homorganic voiced stops versus .13 for nasals and heterorganic voiced stops. Finally, Experiment 3 obtained more errors involving nasals and (partially) homorganic liquids than involving nasals and homorganic voiceless stops. The average for the pairs [m]-[r], [n]-[l], and [n]-[r] is .46, which exceeds the .18 rating for nasals and homorganic voiceless stops. This is again consistent with the experimental findings.

Turning to the long-distance nasal agreement patterns, the similarity ratings for the relevant consonants of Kikongo and Ganda are as follows. The features used in the calculations for Kikongo were: \{[Cons], [Son], [Cont], [Voice], [Lab], [Cor], [Dors], [Nasal]\}. In Kikongo, homorganic and heterorganic voiced stops and approximants participate in nasal agreement, but not voiceless stops. In agreement with this pattern, the average similarity rating for Kikongo homorganic and heterorganic pairs combined is .30 for nasal-voiced stop pairs, but only .17 for nasal-voiceless stop pairs. In addition, the average for nasals paired with the approximant [l] is .28, which is greater than the .17 rating for nasals and voiceless stops.

The feature set used for the Ganda similarity calculations were the same as for Kikongo plus the feature [Anterior]. In Ganda, homorganic voiced stops and approximants interact with nasals in long-distance agreement. Homorganic voiceless stops also participate, but in a more limited way – only when the nasal precedes the voiceless stop in the root. On the other hand, heterorganic nasals and voiced stops can occur together in a root (subject to some limitations). This pattern is consistent with the similarity ratings for Ganda given by the natural classes metric, under which pairs of homorganic nasals and voiced stops (and approximant alternants) have an
average of .37, which exceeds the .21 average for homorganic nasal-voiceless stop pairs, which in turn is slightly more than the .17 average for heterorganic nasal-voiced stop pairs.

The scaling of homorganic nasal-voiceless stop pairs as more similar than heterorganic nasal-voiced stop pairs points to a potential limitation of using participation in nasal agreement as a precise indicator of relative similarity. When the average ratings are narrowed to these subsets in Kikongo, the natural classes metric also gives the homorganic nasal-voiceless stop group as closer at .21 than heterorganic-nasal voiced stop pairs at .13. However, in Kikongo the latter pair interact in nasal agreement, but not the former. Although this might be interpreted as a shortcoming of the similarity computation, that is unlikely because of the following. First, the inventories of Kikongo and Ganda are not vastly different. In both languages, nasal agreement affects homorganic voiced stops. In Kikongo it also affects heterorganic voiced stops, but not homorganic voiceless, while in Ganda it affects homorganic voiceless stops in certain contexts to the exclusion of heterorganic voiced. It would be difficult for any similarity computation to generate a certain ranking of these groups for one language and an opposite ranking for the other. Indeed, it is not clear that this would even be desirable. As described in (4a), the two patterns point to a scaling which is silent on the relative similarity of nasals and homorganic voiceless stops versus nasals and heterorganic voiced stops.

The contrast between the Kikongo- and Ganda-type patterns is suggestive that with respect to long-distance agreement (and possibly other phonological processes), the similarity scaling consists of tiers of sound classes, as depicted in (13) for nasal-oral stop pairs.

(13) Nasal-Oral Stop Similarity Tiers

Tier 1: Nasals/homorganic voiced stops, e.g. m/b, n/d

Tier 2: Nasals/homorganic voiceless stops, e.g. m/p, n/t, and

nasals/heterorganic voiced stops, e.g. m/d, n/b

The top tier contains homorganic nasal-voiced stop pairs. Homorganic voiceless stops and heterorganic voiced stops belong together on a lower tier. Phonological nasal agreement patterns that reach into this lower tier would then be differentiated according to the property selected. They might choose all voiced stops or all homorganic. Thus, while the natural classes metric computes
a fine-grained scaling of similarity, which might be relevant in other areas or processes, phonological agreement phenomena seem to show more coarse-grained effects (for related observations, see e.g., Flemming, 2001; Pierrehumbert, 1990).

In sum, the objective natural classes-based computation of relative similarity is generally consistent with the patterns of segment interaction in English speech errors on the one hand and nasal agreement in Kikongo and Ganda on the other (although the phonological patterns show less fine-grain). Furthermore, it is worth pointing out that the overall similarity rankings obtained by the natural classes metric for categories of nasal-oral consonant pairs for English are consistent with those for Kikongo and Ganda, providing independent support for their comparability.

*The Analysis of Long-distance Agreement.* In finding a correlation in the consonants preferentially affected in long-distance nasal agreement and those that show higher interaction in errors with nasals, this study’s results are consistent with the proposal that long-distance agreement has functional origins in language production (Hansson, 2001; Rose & Walker, 2003; Walker, 2000a, 2000b). Under the view considered here, this functional basis does not represent an intention of the speaker but rather it exerts influence on language change and shapes certain synchronic phonological processes through constraints with grounding in principles of production. This proposal goes beyond the observation that similar sounds show increased interaction in errors and long-distance agreement. It builds upon the existence of certain parallels across the phenomena and posits a kind of causative relation.

One area of parallel involves a shift towards agreement. Sounds that are minimally different present difficulties in speech planning, as evidenced by their increased interaction in misordering and substitution errors. They also present difficulties for speech execution, which can result in errors that are gradient and/or phonotactically ill-formed (Pouplier, 2003; Pouplier & Goldstein, 2002). Speech planning errors that involve similar but different segments frequently render the sounds identical. For example, the similarity of /b/ and /m/ triggers the anticipatory substitution error in *when does the mus for Monticello leave?* (*mus* should be *bus*). Likewise the similarity of [l] and [r] triggers a perseveration error in the production of *Christmas club* as
Christmas crub. (Errors from Shattuck-Hufnagel & Klatt, 1979.) This connects with the proposed functional grounding for phonological long-distance agreement. By requiring that similar but different nasal and oral consonants match in nasality, the grammar preemptively reduces the potential for an error involving nasalization.

A study by Pouplier et al. (1999) found that gradient errors frequently involve the intrusion of a gesture from one segment on another, often without reduction of the target gesture in the affected segment (see also Pouplier, 2003). Such findings reveal that subsegmental units are often independently manipulated in execution errors. Likewise, long-distance agreement often fixes agreement for a particular feature in similar segments. In addition, a number of recent studies discovering the occurrence of inaudible, gradient errors indicate that miscoordination in production occurs far more often than previously conceived (e.g. Frisch & Wright, 2002; Pouplier & Goldstein, 2002; Pouplier et al., 1999). This lends support to the notion that speech production factors could play a significant role in shaping phonological processes.

Taken together, speech error research points to a finding that similar but different sounds pose difficulty in speech production which is improved by a move towards identity. This is captured in spreading-activation modeling of speech errors, in which the phonological encoding of a word or phrase involves node activation for each phonological element. In minimally different sounds, the spreading of activation between the many corresponding feature nodes causes a strong connection to be formed between them, increasing the probability of an ordering or substitution error (e.g. Dell, 1984, 1986; MacKay, 1987; Stemberger, 1985a, 1985b). The difficulty is thus in coordinating the different properties of the highly similar sounds, Matching these properties is a means of resolving this problem.

Applying this to the basis of long-distance agreement, Rose and Walker (2003) suggest that it is a grammaticalized process that accomplishes matching for individual features in similar sounds (see also Hansson, 2001). Building on Walker, Hacopian, and Taki (2002), Rose and Walker speculate that one way in which an agreement pattern could arise is through a scenario in which it presents first as a constraint operating within morphemes. For example, roots containing combinations of consonants which are more prone to participate in a speech error, such as [m]-[b]
or [n]-[d] would be excluded from the lexicon. This could take place in language change, such that offending forms in the lexicon were altered gradually until the exclusion was systematic, and/or it could operate as a synchronic condition. Comparison of cognate morphemes in Chaha, which shows laryngeal agreement among certain consonants in morphemes, and related Amharic, which lacks the agreement, reveals that disagreeing consonants were altered in Chaha to match for laryngeal properties (Rose & Walker, 2003). In languages where the agreement is extended to alternations, the generalization could originate analogically when affixation brings together combinations of consonants that are excluded within morphemes.

The similarity of interacting segments, which is the focus of the present study, and the resulting shift to closer identity agreement, is not the only basis for the hypothesized grounding of long-distance consonant agreement in speech production. It was mentioned earlier that both phenomena also show a capacity for action-at-a-distance. In the agreement-by-correspondence analysis, this is captured through agreement being accomplished via a relation established between similar sounds, which may or may not be adjacent. Hence, the role of similarity and potential for distance interaction go hand in hand.

Hansson (2001) uncovers a further point of contact between speech production and long-distance consonant agreement. His cross-linguistic survey finds that in cases where agreement is not root- or stem-controlled, it is primarily regressive. This means that in a pair of consonants that must show agreement, such as sibilant agreement in the sequence [ʃ]…[s], it is the consonant that comes later in the word that usually controls the outcome, giving [ʃ]…[s] rather than [ʃ]…[ʃ]. Hansson correlates this with the tendency for speech errors to be anticipatory rather than perseverative. The regressive direction of agreement does not stand as a universal property, however. In particular, some patterns of long-distance nasal agreement operate progressively. Likewise, the occurrence of anticipatory errors instead of perseverative ones is not an absolute.

In sum, the results of the present experiments paired with the findings of typological studies of phonological agreement are suggestive that these phonological processes have a functional grounding in principles of speech planning and its execution. That is, synchronic, grammatical constraints can reflect patterns that facilitate speech production.
Further research on this topic could fruitfully evolve in a number of directions. In the area of speech error research, future studies could usefully examine whether parallels exist between error patterns and agreement for other kinds of features. A tongue twister study by Rose and King (2003) has already examined an aspect of this question in Chaha, finding a higher error rate involving pairs of voiceless consonants that do not obey the language’s laryngeal agreement constraint. As Rose and Walker (2003) have pointed out, possible extensions to long-distance vowel harmony should also be explored. Another area that deserves examination is the evolution of phonological agreement patterns. Studying the path of their diachronic development would be informative about the functional origins of agreement patterns and the extent to which they arise through the phonologization of graduated trends in a lexicon versus a more abrupt implementation of a synchronic restriction. An additional direction to examine concerns areas of symmetry with dissimilatory restrictions and processes in phonology. As mentioned earlier, the role of segment similarity in such phenomena are well-documented. They also show the potential for distance interactions. Studying points of commonality between agreement and dissimilatory phenomena as well as their differences will surely shed further light on the nature of these processes.
REFERENCES


Nooterboom, S. G. (1967). Some regularities in phonemic speech errors. *IPO Annual Progress*


1 Combinations of nasals and heterorganic voiced stops are avoided in certain specific circumstances when the nasal precedes the voiced stop: (i) if the root both contains a long vowel and, and (ii) in combination with coronal nasals, although [n]-[g] pairings are permissible. In contrast, the restrictions on nasals and homorganic stops, illustrated in (2), are broader in scope.

2 Hansson (2001) points out a problem that arises under circumstances of an inventory in which a consonant is asymmetrically unpaired within its series for a value of the agreeing feature. See Frisch et al. (in press) for possible solutions to treat such cases.

3 On the treatment of so-called ‘transparent’ voiceless stops in local nasal harmony in terms of local feature spreading, see Walker (2000c).

4 In Ganda, geminate stops (voiceless, voiced, nasal) are also possible.

5 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, /dl/ exists as a separate phoneme in the language.

6 It has been established that more errors occur in production of low frequency words (e.g. as a target words in a critical pair) than in high frequency ones (Dell, 1990; Stemberger & MacWhinney, 1986). This motivates the lexical frequency balancing instituted within groups of critical pair words and within each critical pair. In contrast, errors that form real words do not seem to show outcome-based effects of lexical frequency. Dell (1990:331) finds that in phonological speech errors “there is little tendency for errors to create high-frequency over low-frequency outcomes” (see also Dell & Reich, 1981; Garrett, 1976).

7 Phoneme frequency can also influence substitution errors such that lower frequency phonemes tend to undergo replacement. However, since the SLIPS procedure generates mostly exchange errors, and asymmetries in substituting consonants were not under examination, this is not a primary issue for the present study.

8 I am grateful to Sharon Rose for discussion on this point.
Figure 1

Obeys nasality matching

\[ \eta_\alpha \ i \ k \ i \ n_\alpha \ i \]

[Nasal] [Nasal]

Violates nasality matching

\[ \eta_\alpha \ i \ k \ i \ d_\alpha \ i \]

[Nasal] [Oral]
<table>
<thead>
<tr>
<th>English</th>
<th>Kikongo</th>
<th>Ganda</th>
</tr>
</thead>
<tbody>
<tr>
<td>p t k</td>
<td>p t k</td>
<td>p t c k</td>
</tr>
<tr>
<td>b d g</td>
<td>b d g</td>
<td>b/β d/l j/j g</td>
</tr>
<tr>
<td>m n n</td>
<td>m n l</td>
<td>m n j n</td>
</tr>
<tr>
<td>l r l</td>
<td></td>
<td>(l)</td>
</tr>
</tbody>
</table>
Figure legends

Figure 1. Assessment of feature agreement in corresponding consonants

Figure 2. Stop and liquid inventories
<table>
<thead>
<tr>
<th>Priming Pair</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>cat sass</em></td>
<td>Priming pair 1, rhymes with critical pair</td>
</tr>
<tr>
<td><em>mad pack</em></td>
<td>Priming pair 2, initial CVs match critical pair, but in opposite order</td>
</tr>
<tr>
<td><em>match pan</em></td>
<td>Priming pair 3, initial CVs match critical pair, but in opposite order</td>
</tr>
<tr>
<td><em>pat mass</em></td>
<td>Critical pair</td>
</tr>
<tr>
<td><em>?????</em></td>
<td>Cue to recall critical pair, <em>pat mass</em></td>
</tr>
</tbody>
</table>
Table 2. Speech error categorization: Initial consonant errors

<table>
<thead>
<tr>
<th>Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchange</td>
<td></td>
</tr>
<tr>
<td>Consonant</td>
<td>near tail → tear nail</td>
</tr>
<tr>
<td>Word</td>
<td>mutt puff → puff mutt</td>
</tr>
<tr>
<td>Anticipation</td>
<td>bone mode → moan mode</td>
</tr>
<tr>
<td>Perseveration</td>
<td>numb deck → numb neck</td>
</tr>
<tr>
<td>False start</td>
<td>mile pad → pi—mile pad</td>
</tr>
<tr>
<td></td>
<td>meat beak → beat —</td>
</tr>
</tbody>
</table>
Table 3. Number of errors as a function of voicing, Experiment 1

<table>
<thead>
<tr>
<th>Place</th>
<th>C-Exchange</th>
<th>W-Exchange</th>
<th>Anticipation</th>
<th>Perseveration</th>
<th>False Start</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voiced stop</td>
<td>Bilabial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m-b/b-m)</td>
<td>23</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>13</td>
<td>47</td>
</tr>
<tr>
<td>Alveolar</td>
<td>23</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>48</td>
</tr>
<tr>
<td>Total</td>
<td>46</td>
<td>8</td>
<td>13</td>
<td>7</td>
<td>21</td>
<td>95</td>
</tr>
<tr>
<td>Voiceless stop</td>
<td>Bilabial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m-p/p-m)</td>
<td>12</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>10</td>
<td>29</td>
</tr>
<tr>
<td>Alveolar</td>
<td>25</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
<td>7</td>
<td>5</td>
<td>1</td>
<td>14</td>
<td>64</td>
</tr>
</tbody>
</table>
Table 4.

Number of errors as a function of place, nasal-oral order, and earliness, Experiment 1

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Voiced Stop</th>
<th>Voiceless Stop</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place</td>
<td>Bilabial</td>
<td>47</td>
<td>29</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Alveolar</td>
<td>48</td>
<td>35</td>
<td>83</td>
</tr>
<tr>
<td>Order</td>
<td>Nasal first</td>
<td>46</td>
<td>33</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Oral first</td>
<td>49</td>
<td>31</td>
<td>80</td>
</tr>
<tr>
<td>Earliness</td>
<td>First half of exp.</td>
<td>55</td>
<td>28</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Second half of exp.</td>
<td>40</td>
<td>36</td>
<td>76</td>
</tr>
</tbody>
</table>
Table 5. Number of errors as a function of place, Experiment 2

<table>
<thead>
<tr>
<th>Nasal Place</th>
<th>C-Exchange</th>
<th>W-Exchange</th>
<th>Anticipation</th>
<th>Perseveration</th>
<th>False Start</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Homorganic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilabial (m-b/b-m)</td>
<td>23</td>
<td>8</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>48</td>
</tr>
<tr>
<td>Alveolar (n-d/d-n)</td>
<td>19</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>43</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>42</td>
<td>12</td>
<td>10</td>
<td>11</td>
<td>16</td>
<td>91</td>
</tr>
<tr>
<td><strong>Heterorganic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilabial (m-d/d-m)</td>
<td>3</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>Alveolar (n-b/b-n)</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>9</td>
<td>14</td>
<td>1</td>
<td>3</td>
<td>14</td>
<td>41</td>
</tr>
</tbody>
</table>
Table 6.

Number of errors as a function of nasal place, nasal-oral order, and earliness, Experiment 2

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Homorganic Stop</th>
<th>Heterorganic Stop</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nasal Place</strong></td>
<td>Bilabial</td>
<td>48</td>
<td>21</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Alveolar</td>
<td>43</td>
<td>20</td>
<td>63</td>
</tr>
<tr>
<td><strong>Order</strong></td>
<td>Nasal first</td>
<td>46</td>
<td>19</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Oral first</td>
<td>45</td>
<td>22</td>
<td>67</td>
</tr>
<tr>
<td><strong>Earliness</strong></td>
<td>First half of exp.</td>
<td>60</td>
<td>29</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Second half of exp.</td>
<td>31</td>
<td>12</td>
<td>43</td>
</tr>
</tbody>
</table>
Table 7. Number of errors as a function of manner, Experiment 3

<table>
<thead>
<tr>
<th>Nasal Place</th>
<th>C-Exchange</th>
<th>W-Exchange</th>
<th>Anticipation</th>
<th>Perseveration</th>
<th>False Start</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Liquid</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilabial (m-t/r-m)</td>
<td>30</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>49</td>
</tr>
<tr>
<td>Alveolar (n-l/l-n)</td>
<td>26</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>17</td>
<td>54</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>56</td>
<td>13</td>
<td>6</td>
<td>4</td>
<td>24</td>
<td>103</td>
</tr>
<tr>
<td><strong>Voiceless stop</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilabial (m-p/p-m)</td>
<td>17</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>Alveolar (n-t/t-n)</td>
<td>14</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>31</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>54</td>
</tr>
</tbody>
</table>
Table 8.
Number of errors as a function of nasal place, nasal-oral order, and earliness, Experiment 3

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Liquid</th>
<th>Voiceless Stop</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasal Place</td>
<td>Bilabial</td>
<td>49</td>
<td>28</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>Alveolar</td>
<td>54</td>
<td>26</td>
<td>80</td>
</tr>
<tr>
<td>Order</td>
<td>Nasal first</td>
<td>49</td>
<td>37</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>Oral first</td>
<td>54</td>
<td>17</td>
<td>71</td>
</tr>
<tr>
<td>Earliness</td>
<td>First half of exp.</td>
<td>62</td>
<td>32</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>Second half of exp.</td>
<td>41</td>
<td>22</td>
<td>63</td>
</tr>
</tbody>
</table>
Table 9. Exchange and substitution errors from MIT corpus, reported in Shattuck-Hufnagel and Klatt (1979)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Bilabial nasal</th>
<th>Alveolar nasal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voicing</strong></td>
<td>Voiced stop</td>
<td>24</td>
<td>15</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>(m/b, n/d)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voiceless stop</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>(m/p, n/t)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Place</strong></td>
<td>Homorganic stop</td>
<td>24</td>
<td>15</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>(m/b, n/d)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heterorganic stop</td>
<td>6</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>(m/d, n/b)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Manner</strong></td>
<td>Liquid</td>
<td>20</td>
<td>41</td>
<td>61</td>
</tr>
<tr>
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<td>(m/r, n/l)</td>
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<td>(m/p, n/t)</td>
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Table 10. Phoneme error rates and frequency

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<th>Phoneme</th>
<th>Error rate (%)</th>
<th>Frequency (%)</th>
<th>Denes</th>
<th>Shattuck-Hufnagel and Klatt</th>
<th>Mean</th>
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<td>5.3</td>
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