Published in final edited form as:
Lang Cogn Neurosci. 2014 ; 29(10): 1325–1341. doi:10.1080/23273798.2014.917193.

Effect of sound similarity and word position on lexical selection

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Abstract

Spoken word production research has shown that phonological information influences lexical selection. It remains unclear, however, whether this phonological information is specified for its phonological environment (e.g., word position) or its phonetic (allophonic) realization. To examine this, two definition naming experiments were performed during which subjects produced lexical targets (e.g., "balcony") in response to the targets' definitions ("deck higher than a building's first floor") after naming a series of phonologically related or unrelated primes. Subjects produced target responses significantly more often when the primes were phonologically related to the target, regardless of whether the phonologically related primes matched the target's word position or did not. For example, subjects were equally primed to produce the target "balcony" after the prime "ballast" or "unbalanced" relative to unrelated primes. Moreover, equal priming occurred irrespective of phonological environment or phonetic realization. The results support models of spoken word production which include context-independent phonological representations.

Keywords

spoken word production; phonological encoding; lexical access; phonological representations

Introduction

Models of spoken word production agree on the existence of at least two stages of processing (Levelt, 1989): a high-level lexical-semantic stage at which lexical items are retrieved from semantic memory and mapped onto an abstract lexical representation and a low-level phonological stage at which the sounds of a word are prepared for articulation. Psycholinguistics research has debated about the representations at each substage of spoken word production, as well as the extent to which information flows between adjacent stages (Dell, 1986; Rapp & Goldrick, 2000). The current research seeks to examine the representation of abstract phonological units and their ability to independently impact lexical-semantic processing. In particular, this study will investigate the extent to which information at the phonological stage impacts processing at the lexical stage, and whether these phonological representations are position-sensitive and specified for acoustic realization in a given environment.

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Current models of spoken word production implement two substages during which phonological information about a word is available. First, abstract information about the phonemes becomes available during access to the word form; second, during preparation for articulation, this information is specified for each phoneme's relative position and phonetic realization. Evidence for this division between abstract and phonetically-specified representations is reported in both patient and covert speech research.

Buchwald and Miozzo (2011) report the repetition shadowing patterns of a patient with aphasia who showed a frequent word-initial s-deletion deficit. In English, stop consonants which follow /s/ word-initially are unaspirated, whereas word-initial voiceless stops are aspirated (Klatt, 1975). Buchwald & Miozzo's patient produced stops which followed these rules even after an s-deletion as if the preceding /s/ were never present; that is, he produced utterances with aspirated initial stop consonants (e.g., "p^hil" following s-deletion of intended "spill"). The authors argue that since the word position of the stop consonant was specified after the deletion, the original target could not have been specified for phonetic position. Other studies have identified similar cases with specific deficits for abstract phoneme representations (Béland, Caplan & Nespoulous, 1990; Goldrick & Rapp, 2007; Ash et al., 2011).

Studies which use covert speech (or "inner speech"), during which subjects retrieve a lexical form but must suppress articulation, also suggest a division between the lexical-phonological word form and the fully specified articulatory output. During a covert speech task, subjects necessarily activate the abstract phonological forms but do not need to complete acoustic specification. Oppenheim and Dell (2008) presented subjects with four-word lists and analyzed self-reported errors when subjects were asked to rehearse the lists either overtly or covertly. Both covert and overt speech showed a lexical effect, such that subjects reported errors that were much more likely to be words than nonwords ("reef leach" →"leaf reach" was more common than "heath leech" → "leath heach"). This lexical effect, which is robust among speech errors (Dell & Reich, 1980), reflects activation of a lexical-phonological representation during both overt and covert speech. However, only the overt speech showed a phonemic similarity effect: there was a tendency for more phonetically similar phonemes to be exchanged ("reef" → "leaf", with only one altered phonetic feature, was more likely that "reef" → "beef"). Covert speech showed no phonemic similarity effect, suggesting that the activated representations for the covert speech were not sensitive to the phonetic properties of each phoneme. An alternative explanation is that overt speech limits the opportunity for self-repair of errors through an internal monitoring mechanism (Postma, 2000), but Oppenheim & Dell concluded that covert speech is "impoverished" in that it is unspecified for phonetic detail.

Although the existence of separate stages of phonological processing is widely accepted, it is less clear how these two substages of phonological processing differentially influence access to the lexical word form. If phonological information influences lexical selection, heightened activation of a word's phonemes will increase the likelihood that the word will be produced. For example, a speaker who is trying to think of a word for the deck outside his second-story hotel room might activate the words "balcony" and "veranda", and the semantic representations of each word will compete for selection based on their relevance, frequency, and the recency with which the speaker has used them, among other factors. If the speaker has recently used the word "ballast", the first three phonemes of "balcony" may still be residually activated. If these phonemes share residual activation with the lexical entry for "balcony", the activation of "balcony" during lexical selection will be boosted relative to that of "veranda".

There is evidence from both cloze sentence completion and tip-of-the-tongue states that phonological information has some influence on lexical-semantic processes, but these studies do not distinguish between the abstract and phonetically specific levels of phonological processing. Rapp and Samuel (2002) asked subjects to fill in the final words of open-ended sentences. The rate with which subjects used a given word was modulated by whether a rhyme for that word appeared earlier in the sentence. Subjects were more likely to choose a word if a phonologically similar word had already been activated (e.g., "The man walked into the bank and slipped on some ice. He'd gone to deposit his *payment/check* and nearly broke his ________."; target, "neck"). Ferreira and Griffin (2003) used a similar paradigm and found that subjects were more likely to produce a word if either a semantic competitor or a *homophone* of a semantic competitor was present in the preceding sentence (e.g., "nun" and "none" both increased the likelihood of a "priest" response). These findings indicate that lexical selection of a target ("neck", "nun") is influenced by the activation of words with shared phonology ("check", "none").

Tip-of-the-tongue (TOT) research has found similar effects. This line of investigation attempts to characterize the phenomenon in which speakers have accessed some aspects of a word's form, e.g., first phoneme, metrical structure, or number of syllables, but fail to fully encode and produce the intended word. The TOT effect was first induced experimentally by Brown and McNeill (1966), who presented subjects with the definitions of infrequent words and asked them to report whether they knew the words being defined or if they were "stuck" in a TOT state. Later studies have shown that exposure to phonologically related primes before presentation of the target definitions increased the number of target responses and decreased the number of TOT states reported (James & Burke, 2000; Meyer & Bock, 1992). It also decreased the number of non-target responses (Perfect & Hanley, 1992), suggesting that the locus of the phonological priming effect is lexical access rather than phonological encoding. If the effect of priming was simply to facilitate encoding of the sounds of the target word, the identity of the response would not be affected.

The studies described above provide ample evidence that phonological activation influences lexical access. However, these studies used phonological primes which matched the target in word position and phonetic realization. It has not been shown whether the phonological representations which show this influence are specified for the position and phonetic information which is not available until the latest stage of production. If the sound units which influence lexical selection are specified for word position and phonetic realization, then activated phonemes should fail to show any influence on word selection unless they match the target word's position and/or phonetic context. For example, the /b/ in "unbalanced" is in a different context (/n_a/ or C_V) than the /b/ in "balcony" (/#_a/or #_V). Likewise, voiceless stops are produced differently in English when they begin a stressed syllable (aspirated) then when they do not (unaspirated). If the /p/ representation in "apron" is specified as "unaspirated" or "word-medial", then it should fail to prime the aspirated initial /p/ in "principal". On the other hand, if these representations are abstract, then any /p/ realization should prime all other /p/'s.

Although the spoken word production literature has not addressed this question, the auditory word recognition literature suggests that at least some aspects of word retrieval are influenced by phonological priming independent of a phoneme's word position or realization. Subjects are able to identify words whose onsets are embedded in the middle of other words or nonwords (Norris, McQueen, & Cutler, 2002). Luce and Cluff (1998) found that subjects access the semantics of embedded words; they made facilitated lexical decisions for target words which were semantically related to an embedded word in the prime (e.g., "key" primed by "hem*lock*"). Van Alphen and van Berkum (2010) also found that the N400, an ERP measure of violated semantic expectations, was modulated by whether a stimulus sentence contained a semantically relevant word embedded in an otherwise semantically incoherent word. That is, subjects showed semantic processing of the word "pain" when they heard the word "champagne" in a sentence about an injury.

It is unknown whether abstract phonological representations influence lexical access in production. To this end, the current research investigates whether phonological information can influence the selection of a word when preceding phonological primes are presented in a different position than the target (Experiment 1) or when this information is presented in a different allophonic context than the target (Experiment 2). If lexical access is only primed by the production of phonological information which matches the target word in word position and phonetic realization (e.g., 'balcony', 'ballast'), then the sound forms which influence lexical selection are specified for both their phonetic position and articulatory properties. If, on the other hand, positionally and acoustically different forms also prime lexical access (e.g., 'balcony', 'cannibal'), then the units of phonological information which influence lexical access are abstract.

Experiment 1

The goal of experiment 1 is to investigate the effect of phonological information on lexical selection, and in particular to determine whether phonological priming is possible for sounds which share abstract phonemic information, but not their word position. Experiment 1 adopts a modified TOT definition naming paradigm, modeled after James & Burke (2000). James & Burke presented subjects with the definitions of low-frequency target words and asked them if they could identify the word being defined, and if not, whether they were in a TOT state. Each definition was preceded by ten visually presented prime words, which subjects overtly produced. Trials were in one of two conditions: Unrelated, in which primes were not semantically or phonologically related to the target; and Phonologically Related, in which five of the primes shared some phonemes with the target (e.g., for the target "sextant": "*sec*ondary", "*se*mblance", "re*st*rain", "pheas*ant*", "fei*nt*"). Five filler words were used in each trial in the Related condition to prevent subjects from using the primes as a strategy to identify the target (a concern raised by Hamburger & Slowiaczek, 1996; Sullivan & Riffel, 1999; Monsell & Hirsh, 1998; and Norris, McQueen, & Cutler, 2002). James & Burke were interested in the effect of phonological information on TOT states in different age groups. The phonological information always appeared in the same word position in the prime and target and they did not control for repetition of primed information or for the amount of phonological overlap (e.g., "ant" in "pheasant" vs. "nt" in "feint") nor did they ensure complete overlap between the target and its corresponding set of primes (e.g., the /k/ in "sextant" is never primed).

The current experiment uses a similar task but more highly controlled phonologically related stimuli, and manipulates the word position of the overlapping phonemes between the prime and target. Because this is a priming study and not a TOT investigation, we did not collect data on TOT experiences, nor did we attempt to elicit TOT states; rather, we investigated the proportion of trials on which subjects selected and produced the target word.

Stimuli

Seventy-two three-to-five syllable words were selected as potential stimuli from previous studies (Meyer & Bock, 1992; Burke, McKay, Worthley & Wade, 1991; Harley & Brown, 1998; Morsella & Kraus, 1999) and from the MRC Linguistic Database (Coltheart, 1981). Definitions were adapted from the Merriam-Webster dictionary to between six and ten words each, to provide consistency across stimuli and to minimize variation in reading times.

Targets were selected from a pool of 106 words during a norming pilot experiment in which 15 subjects named the candidate target words in response to their definitions. In order to minimize variation in difficulty between items, targets were eliminated if fewer than 60% of pilot subjects named the target word. Targets were also eliminated if the mean naming latency across conditions and subjects was longer than 4000 ms. The mean number of words per definition in the 72 selected target words for Experiment 1 was 8.18 (SD 1.23) and the average Kučera-Francis frequency (Kučera & Francis, 1967) of each target word was 18.34 (SD = 47.5).

In the experiment proper, a single trial consisted of the presentation of six prime words presented one at a time, followed by the definition of a target word. Subjects were told to produce each prime word aloud and then indicate by button press whether they thought they had pronounced it correctly. Subjects were told that when presented with a definition, they were to produce the word being defined as quickly as possible, and then indicate by button press whether they had pronounced it correctly.

In every trial, three of the six primes were fillers which were phonologically and semantically unrelated to the target. The other three primes (or, in rare instances, compound words, e.g., "dry cleaner") were in one of three conditions. In the Control condition, all primes were phonologically unrelated to the target. In the Match condition, three of the six primes contained the same initial, middle, or final syllable as the target word (e.g., for the target "balcony", "*bal*last", "re*con*cile", "villa*iny*"). The shared syllables were in the same word position as the target. In the Mismatch condition, three primes contained the initial, middle, and final syllable of the target word in a different word position (e.g. for the target "balcony", "un*bal*anced", "*con*tagion", "cra*ni*um"). No primes across conditions were semantically related to their targets.

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For targets with four or more syllables, the medial syllable with primary or secondary stress was selected for overlap with a prime. To account for ambisyllabicity in English, any consonant which could be both the coda of the preceding syllable and the onset of the following syllable (e.g., the /l/ in "calorie") was treated as both part of the onset and part of the coda.

Three unrelated filler words were also used for each trial to reduce the likelihood that subjects would use a strategy. Match and Mismatch primes were used as fillers for phonologically unrelated targets; for example, the Match primes for the target "balcony" for one subject might be used as unrelated fillers for the target "studio" for another subject. This controlled for frequency differences between primes, since every prime was presented to one-third of all subjects in each condition. No subject saw a prime more than once and no subject reported employing a strategy to use phonologically related primes to identify targets. The six primes, including both critical and filler words, were presented in random order before their corresponding target.

Each of the 72 targets was presented to every subject once, such that any given subject was presented with 24 targets in each of three conditions. The stimuli presented in each condition were counterbalanced for difficulty; difficulty was estimated using the mean target reaction time of participants in the pilot study. Order of presentation was not counterbalanced except that each block of trials (three blocks in Experiment 1, two blocks in Experiment 2) contained the same number of trials in each condition. Additionally, the pattern of response results is the same in each presentation block for both experiments. See Appendix A for a listing of the stimuli.

Procedure

Stimulus presentation was controlled using the BLISS software suite (Mertus, 2002) on a Dell PC. Verbal responses were recorded using a Sony microphone and an Edirol R-09 24-bit Digital Recorder. Responses were recorded as 24-bit uncompressed WAV files sampled at 44.1 kHz, and then down-sampled, using BLISS, to 16-bit WAV before analysis.

Thirty-three subjects (8 male) participated in the experiment and all received payment for their involvement. All participants were native English speakers, reported normal hearing and had no known history of neurological disorders. Each subject gave written informed consent in accordance with the guidelines established and approved by the Human Subjects Committee of Brown University. Data from three subjects were discarded due to a failure to meet an a priori response criterion of 67% correctly produced targets. The experiment took approximately 40 minutes to complete.

Participants were seated in front of a screen and button box and were visually presented with all primes and target definitions. Each trial consisted of the 6 prime words followed by a definition. Figure 1 shows the experimental design and an example trial in each condition. Subjects were asked to read each word aloud as quickly as possible without sacrificing accuracy, then to indicate on the button box whether or not they had pronounced it correctly. After each set of six primes, the target definition was presented. Subjects were asked to produce the word best described by the definition, and then to indicate by button press whether they had pronounced it correctly. Experiment 1 was self-timed unless a subject did not respond within 12000 ms, in which case the response was scored as a timeout and the next trial was initiated.

Responses were scored as correct if the subject named the target word. If a subject changed his or her mind and produced the correct target after a nontarget response or a meaningless utterance such as “uh”, the response was scored as correct, irrespective of reaction time latencies.

Reaction times (RTs) were measured from the onset of sentence definition to the fully correct response; for example, the RT of a response, “b… balcony” would be measured from the presentation of the definition to the onset of the second “b”. This metric was used to ensure that the phonological form of the word had been accessed before the utterance onset. RTs were measured for all correct responses using the waveforms on BLISS. For the RT analysis, RTs were discarded if the subject’s response was more than two standard deviations above his or her mean RT for that condition or if the target had fewer than 20 measured reaction times across participants (i.e., fewer than 67% of participants correctly named the target).

Results

Target responses—Figure 2 shows the mean number of correct responses to the target across conditions (Match, M = 0.851; Mismatch, M = 0.854; Control, M = 0.811). As can be seen, both the Match and Mismatch conditions increased the proportion of correct target responses relative to the Control condition.

A one-way ANOVA confirmed these observations. There was a main effect of condition in the within-subject analysis (F[2,28] = 3.45, MSE = 0.017, p = 0.038, Figure 2a) and marginal effect in the item analysis (F[2,70] = 2.76, MSE = 0.042, p = 0.067, Figure 2b). We attribute the weaker effects in the within-subject analysis to the high variability of difficulty across items.

Post-hoc pairwise two-tailed t-tests showed a difference for the subject analysis between the Match and Control conditions (subject analysis: t[29] = 2.53, p = 0.017) and a marginal difference in the item analysis (t[71] = 1.78, p = 0.080), as well as significant differences between the Mismatch and Control conditions (subject analysis: t[29] = 2.21, p = 0.035; item analysis, t[71] = 2.17, 0.034), but no difference between Match and Mismatch conditions. These results indicate that the phonologically related conditions improved the likelihood that subjects produced the target, e.g., “balcony”, and that this effect emerged irrespective of syllable position. This pattern of results holds even if we eliminate trials during which subjects gave multiple responses (“veranda… balcony”, accounting for 1.4% of total responses) or if we eliminate the ‘hesitation’ trials (“uh… balcony”, accounting for 2.4%).

Because ANOVA-type tests are nonideal for binomial dependent variables (Jaeger, 2008), we also ran treatment-coded comparisons between pairs of conditions using a mixed logit model, using lme4 (Bates, Maechler, & Bolker, 2012) in R (R Foundation for Statistical

Computing, 2011). The dependent variable was target response, and the model used maximal random effect structure (Condition was included as a fixed effect as well as Subject and Item as random effects). The pattern of significance was the same as the analyses above: there was a significant difference between both the Match and Control ($z = 2.15$, $p = 0.031$) and Mismatch and Control ($z = 2.28$, $p = 0.026$) conditions. A Helmert-coded model was also tested to further examine differences between conditions. One contrast used coefficients that grouped together the Match and Mismatch conditions and compared them to the Control condition ($z = 2.57$, $p = 0.010$), and a second contrast compared the Match and Mismatch conditions ($p > 0.1$). These contrasts confirm the pattern of results above.

Nontarget response analysis—When subjects failed to give a correct target response, these responses were coded based on what type of error was made. These types included: the production of a semantic competitor, a word which did not fit the definition, a nonword, a phonologically related word to the target, an expressed TOT state, a mispronunciation of the target, a partial but incomplete production of the target, and a failure to respond within 12 seconds. The two most common types of errors were production of semantic competitors, e.g., "veranda" in response to the definition of "balcony"; and a failure to respond within the response window, which was coded as a timeout. These responses were still relatively rare, accounting for 9.8% of error types. Nonetheless, the pattern of differences between conditions is of interest to the question of what drives the target response effect. Qualitative analysis revealed that the proportion of semantic competitor responses was highest in the Control condition, but the proportion of timeouts did not differ between conditions. See Table 1 for a summary of the response types in Experiment 1.

Reaction time analysis—Figure 3 shows the RT results. A one-way ANOVA indicated there was no effect of reaction time across conditions in the subject analysis ($F[2,28] = 1.35$, $MSE = 107837$, $p > 0.1$), but there was a marginal effect of condition in the item analysis ($F[2,70] = 2.64$, $MSE = 347679$, $p = 0.078$, Figure 3b). Post-hoc pairwise comparisons showed marginally higher reaction times in the Match condition than in the Control condition in the subject analysis ($t[29] = 1.73$, $p = 0.094$) and significantly higher reaction times in the item analysis ($t[65] = 2.25$, $p = 0.028$). No other comparisons were significant.

Discussion

It was the goal of Experiment 1 to investigate the extent to which phonological priming of lexical access is sensitive to word position of the primed sound units. The data showed a significant effect of phonological priming even when the primes did not match the target's word position. There was also no difference in the proportion of target responses between the Match and Mismatch conditions, suggesting that there is no priming advantage to the position-matched primes over the mismatched primes.

Most trials during which subjects did not name the target were either semantic competitor responses (e.g., balcony-veranda) or timeouts (no response). In Experiment 1, the proportion of semantic competitor responses was not equally distributed across conditions. There were fewer semantic competitor responses in the phonologically matched conditions than in the Control condition, suggesting that the increased activation of the phonological properties of a word result in its selection over semantic competitors. On the other hand, timeouts did not differ across conditions.

Experiment 1 also showed slower reaction times in the Match condition than in the Control condition. These slowed response latencies in the Match condition may reflect competition between the phonologically unshared portions of the prime and target. For example, the phonological segments of “last” in “ballast” compete with the unshared segments “cony” in the target word “balcony”. Consistent with this interpretation is evidence that slowed response times during word naming are proportional to the number of unshared phonemes between target words and competing lexical items (Wheeldon, 2003; Dufour & Peereman, 2003). Indeed, Sevald & Dell (1994) and Sullivan & Riffel (1999) conclude that articulatory plans are constructed sequentially from initial to final sounds, even though early phonological encoding occurs in parallel. As a consequence, the slowed RT latencies in the Match condition could be due to the greater competition during articulatory preparation from primes which matched the target word than from the unrelated Control primes. Consistent with this interpretation is the failure to show a difference in RT latencies between the Mismatch and Control conditions. Here, phonological planning and implementation stages are not influenced by the phonological prime because they occur in different “slots” within the word frame.

Experiment 2

The response data from Experiment 1 support the notion that context-independent phonological representations influence lexical access (Stemberger, 1990; Buchwald & Miozzo, 2011) since there was no difference in the magnitude of the effect for either type of phonological prime (whether or not they matched the syllable context of the target). However, in the Mismatch condition, some of the primes shared phonetic properties with the target and in other cases they did not. For example, on some Mismatch trials, the syllables in the prime and target shared syllable stress, e.g., “*bal*cony” and “un*bal*anced”. On other trials, the prime and target stimuli differed in syllable stress, e.g., “inter*sec*tion” and “*sec*retary”. The same was true for other aspects of phonetic realization (e.g., the /k/ in “balcony” is unaspirated, but the /k/ in its prime “contagion” is aspirated). Thus, it is unclear whether the phonetic realization of a mismatched phonological prime influences the activation of the lexical representation of a target word.

To address this possibility, Experiment 2 manipulated the phonetic similarity between the prime and target stimuli by examining the effects of two Mismatch conditions: one in which the position of the primed syllable varies but the phonetic realization of the target is similar to that of the target stimulus, and one in which both the phonetic position and the phonetic realization of the prime stimulus vary in relation to the target stimulus. If phonological priming of lexical selection is influenced by the similarity between the phonetic realization of the prime and target, then the two Mismatch conditions should differ in the proportion of target responses. If, on the other hand, lexical selection processes are driven by abstract phonological representations, then the Mismatch Phonetics condition will show the same proportion of target responses as the Match and Mismatch Position conditions.

Stimuli

Sixty-eight three- to five-syllable targets were used in Experiment 2. Fifty-six of these targets were used in Experiment 1; the other twelve were selected from an earlier norming pilot. Some targets from Experiment 1 were not included in Experiment 2 because suitable prime words were not available. An independent t-test showed that there were no significant differences in frequency between the stimuli used in Experiment 1 and Experiment 2 ($t[126] = 0.08$; $p > 0.1$).

Following the methods of Experiment 1, subjects were presented with target definitions following the presentation of six consecutive prime words. As in Experiment 1, definitions were adapted from the Merriam-Webster dictionary to between six and ten words each (average number of words per definition: 8.29 (SD = 1.23); average Kûcera-Francis frequency: 22.3 (SD = 54.5). The primes were in one of four conditions. In the Control condition, all six primes were phonologically unrelated to the target. In the Match condition, three of the six primes contained the same initial, middle, or final syllable as the target word. These shared syllables were in the same word position as the target and they matched the target in phonetic realization (e.g., for the target "balcony", "*bal*last", "re*con*cile", "villai*ny*"). In the Mismatch Position condition, three primes shared a syllable with the target word; the shared syllable occurred in a different word position from the target syllable but shared the acoustic realization of the target syllable (e.g. for "balcony", the primes were "un*bal*anced", "outspo*ken*", "cra*ni*um"). In the Mismatch Phonetics condition, both the word position and the acoustic realization of the shared phonemes differed from the target. For example, for "balcony", the primes were "counter*bal*ance" (syllable stress), "*con*tagion" (aspiration of /k/), "*nee*dle" (syllable stress). Parameters along which acoustic realization was manipulated were: stress (con*ver*sion-shi*ver*); vowel quality (*ab*acus-di*ab*olic); aspiration of stop consonants (*cal*endar-lo*cal*ize); /l/-darkening (ado*les*cent-*les*sening); tapping of /t/ and /d/ or stop consonant release (*bat*tery-wom*bat*); /n/-velarization (*in*somnia-dis*in*clined); and vowel nasalization (*gra*duate-pome*gra*nate). Table 3 shows the distribution of these parameters across the stimuli in the Mismatch Phonetics condition. See Appendix B for a listing of the stimuli.

Procedure

Like in Experiment 1, subjects were seated in front of a computer and were visually presented with primes and target definitions. A trial consisted of the presentation of six primes and one target definition. After each prime, subjects were asked to produce the word aloud and then indicate on a button box whether or not they had pronounced it correctly. During a definition presentation, they were asked to produce the word which best fit the definition and then indicate by button box whether they had pronounced it correctly. Because the mean reaction time for subjects in Experiment 1 was less than 3000 ms and the distribution showed very few responses over 4000 ms, the time window for a response was 6000 ms, shortened from the 12000 ms in Experiment 1. Three practice trials were conducted before the experiment to acclimate participants to the procedure and timing of the experiment.

Targets were presented in the same manner as Experiment 1, such that each subject received 17 targets in each condition. Thirty-three native English speakers participated (10 male) and reported no known neurological disorders. None of the Experiment 1 participants participated in Experiment 2. Participants were compensated for their time and provided written informed consent in accordance with the guidelines established and approved by the Human Subjects Committee of Brown University. Data from 3 participants were discarded due to extremely low rate of correct target responses (<67%, the same criterion as Experiment 1). Scoring and analysis of responses were identical to Experiment 1.

Results

Target responses—Figure 4 shows the proportion of correct target responses across conditions (Match, M = 0.839; Mismatch Position, M = 0.820; Mismatch Phonetics, M = 0.827; Control, M = 0.775). A one-way ANOVA showed a marginal main effect of condition in the subject analysis ($F[3,28] = 2.67$, MSE = 0.024, $p = 0.052$, Figure 4a) and a significant main effect in the item analysis ($F[3,66] = 2.93$, MSE = 0.057, $p = 0.035$, Figure 4b). Post-hoc t-tests showed a significant difference between Match and Control conditions in the subject ($t[67] = 2.19$, $p = 0.036$) and item ($t[67] = 2.86$, $p = 0.006$) analyses; a marginal difference between Mismatch Position and Control conditions in both subject ($t[29] = 1.93$, $p = 0.064$) and item ($t[67] = 1.79$, $p = 0.077$) analyses; and a marginal difference between Mismatch Phonetic and Control conditions in the subject analysis ($t[29] = 1.83$, $p =0.078$) and a significant difference in the item analysis ($t[67] = 2.18$, $p = 0.033$). The Match, Mismatch Position and Mismatch Phonetics conditions did not differ from each other (all p-values > 0.10).

In a mixed logit model as described in Experiment 1, the pattern of results was the same: the Match vs. Control ($z = 2.82$, $p = 0.005$), Mismatched Position vs. Control ($z = 2.00$, $p = 0.045$) and Mismatched Phonetics vs. Control ($z = 2.32$, $p = 0.021$) were the only comparisons that yielded significant differences. As in Experiment 1, a Helmert-coded model contrasted the Control with the mean of the other conditions and showed a significant effect ($z = 2.99$, $p < 0.01$), but no effect for any contrasts between phonologically related conditions ($p > 0.1$).

Nontarget responses—The proportion of semantic competitor (e.g., balcony-veranda) and timeout (no response) trials were also analyzed (Table 2). Although there were very few datapoints to evaluate (these responses occurred in only 8.5% of trials), a qualitative analysis of the pattern of results revealed that the mean proportion of semantic competitor responses was higher in the Control condition than the Match and Mismatch conditions, similar to the findings in Experiment 1. The proportion of timeouts and other response subtypes (false starts, phonological competitors, etc.) were also too infrequent to analyze. As in Experiment 1, removing the trials on which subjects produced multiple responses (0.2% of the total) or those on which subjects hesitated (5.5% of responses) did not change the pattern of results.

Reaction times—The RT data were subject to the same analysis cutoffs as the Experiment 1 data. The overall distribution of reaction times was extremely similar to Experiment 1, suggesting that the shortened response window did not impact subjects' responses.

However, no significant main effect or simple effect emerged in either the subject (Figure 5a) or the item (Figure 5b) analyses.

Discussion for Experiment 2

The goal of Experiment 2 was to investigate whether the lexical selection of a target word requires a phonetic match between the prime and the target. The results of Experiment 2 replicated the target response data from Experiment 1. Phonologically related primes increased the rate of target responses in both the Match and Mismatch Position conditions relative to the Control condition. Furthermore, the effect emerged in the Mismatch Phonetics condition, where neither the syllable position nor the acoustic realizations of shared phonemes matched the target. This finding provides strong support for models of spoken word production in which abstract phonological representations influence lexical access.

It is possible that the failure to show a difference between the two Mismatch conditions was because the phonetically mismatched stimuli were not perceptually distinct. To explore this possibility. we conducted an additional experiment. Four subjects from Experiment 2, two male and two female, were randomly selected and their recorded utterances were used as stimuli in a speaker identification task. Each target response in either of the Mismatch conditions was paired with a randomly selected prime utterance, e.g., “cannibal” and “balcony”. Match primes were also randomly paired with each other as filler trials. Five subjects who did not participate in Experiment 2 were auditorily presented with word pairs and asked to identify whether the speaker was the same for both words, or different. There were a total of 86 critical trials and 93 filler trials, presented in random order. In critical trials, the speaker was always the same, and in filler trials, the speaker was different. All five subjects gave slower “same” responses to the Mismatch Position pairs than to the Mismatch Phonetics pairs (Figure 6; paired $t(4)=8.35$, $p=0.001$). The Mismatch Position condition had more phonetic overlap with the target word than the Mismatch Phonetics condition suggesting that subjects experienced interference in the speaker identification task when there was greater phonetic overlap. In any case, these findings indicate that there is a significant perceptual difference between the stimuli in the two Mismatch conditions, and the lack of difference between them in Experiment 2 was not due to a failure to perceive phonetic distinctions across the 2 Mismatch conditions.

In contrast to Experiment 1, the RT analysis showed no difference between conditions. The implications of these findings are discussed below.

General Discussion

The results of Experiments 1 and 2 show that phonological information has an influence on lexical selection, and that this influence is independent of both position and phonetic context. Experiment 1 showed that phonological priming increases the proportion of target responses regardless of whether the position matched between prime and target. Experiment 2 replicated this finding and extended it to trials in which neither the syllable position nor phonetic realization are shared between prime and target. These findings together support models of spoken word production which posit abstract phonological representations. Furthermore, the failure of the Match condition to show a stronger effect than any of the

Mismatch conditions suggests that phonetically specified representations have little effect on the priming of lexical-level processes, compatible with the view that there are restrictions on the extent to which interaction is possible between the underlying phoneme representations and the phonetically specified articulatory output (Goldrick, 2006; Rapp & Goldrick, 2000). It is noteworthy that in the current paradigm, subjects articulated the primes in addition to reading them, requiring the activation of the fully specified phonetic form of each prime. In spite of this activation, the phonetic detail failed to influence lexical access.

An alternative explanation for these results is that perhaps the target response effects in the Match and Mismatch conditions are being driven by the overall acoustic similarity between prime and target words, which is not present in the Control condition. This would be possible if, for example, the lexicon is structured such that any given word form reflects a multidimensional phonetic space that includes a range of acoustic properties which could be mapped onto an exemplar of that word. In the Match and Mismatch conditions, the critical syllables from the primes are within that phonetic space for the target words and therefore prime access to the target word; in the Control condition, the primes are not in that phonetic space and thus no priming occurs. This explanation would not necessitate explicit representations of abstract phonological units. However, of interest, the results are consistent with the hypothesis that the phonetic space belonging to a target word is accessible even when the position of overlapping sound information does not match the sound's position in that word. The results of both experiments also suggested that phonological priming impacts production of semantic competitors. The pattern of results supports the hypothesis that the phonologically related trials impact lexical selection processes, since phonological priming both increases the proportion of target responses and decreases the proportion of semantic competitor responses (Ferreira & Griffin, 2003; Rapp & Samuel, 2002; but see Jaeger et al. 2012, who found an inhibitory effect of phonological overlap).

These priming effects are somewhat surprising in light of the speech error literature, which shows a strong bias towards preserving the word position of phonemes during exchange errors between words (MacKay, 1969; Shattuck-Hufnagel, 1987). This phenomenon in speech errors suggests that such errors occur in the motor plan of already-specified phonological units. However, the current results indicate that the motor plan and implementation of phonetic detail do not influence access to the lexical form of a word. They also suggest that although parallel structure is common during speech errors, priming effects transcend syllable and word boundaries.

Experiment 1 showed slower RT latencies for the production of target responses in the Match condition compared to the Control condition. This finding suggests that a partial phonological match between prime and target words slows phonological planning and articulatory implementation by increasing competition between mismatched phonemes. The failure of Experiment 2 to replicate the reaction time effect in Experiment 1 may be due to the reduced response window from 12 seconds to 6 seconds in Experiment 2, forcing mean latencies in each condition to converge.

Because the stimuli were presented visually, it is possible that there was some effect of orthographic similarity when the phonologically overlapping syllable had the same spelling in both the prime and the target. For example, Damian and Bowers (2002) found that during a form-preparation task, overlapping initial sounds only showed priming if the onsets matched orthographically as well; that is, subjects could more quickly produce “kidney” if they had learned to pair it with “kennel” than if they had learned to pair it with “camel”. However, form-preparation paradigms involve extensive visual exposure to the prime-target pairs during the memorization phase, and the current experiments required only a single exposure to each prime and no visual exposure to the target. Additionally, subjects were asked to focus on the pronunciation of each prime word, not its spelling.

To ensure that orthographic overlap was not driving the current results, we analyzed a subset of trials on which at least two of the three critical syllables did not share their orthography with the target (for example, target “audible”, primes “*od*yssey”, “wil*deb*eest”, “canni*bal*”). There were not enough trials to conduct a statistical analysis on this subset of the data, but the pattern of results resembled that of the full dataset for both experiments. In particular, the mean proportions of all Match and Mismatch conditions were higher than those for their corresponding Control conditions. This pattern is compatible with findings that phonological overlap is sufficient for priming in production without orthographic overlap (Lukatela & Turvey, 1994), and that orthographic overlap does not show priming effects during production tasks which do not require explicit consideration of a word’s spelling (Bi, Wei, Janssen, & Han, 2009).

It should be noted that our description of spoken word production has assumed, for convenience, that the phoneme is the fundamental sound representation in spoken word production. However, because our primes and targets shared full syllables, the same results would be predicted if the basic units of phonological processing were syllables (Levelt & Wheeldon, 1994), completely unspecified phonemes (Roelofs, 1999), or phonemes which are specified for syllable position but not for contextual environment (Dell, 1986, Collins & Ellis, 1992). Our broad interpretation of the results is compatible with any of these proposed phonological representations. This experiment expressly aimed to investigate the specification of word position and acoustic realization during lexical-semantic access. The data indicate that neither of these parameters needs to be specified to elicit priming during the definition naming task.

Because three target syllables were primed in each trial of the current experiments, we cannot distinguish between the effects of priming onsets and rhymes. There is evidence that word onsets have a special status in word form representations; they are often available during TOT states (Brown & McNeil, 1966), priming of naming latency is greater when primes and targets share onsets (Schiller, 2004), and onsets are most often the locus of speech errors (Shattuck-Hufnagel, 1987). Indeed, Jaeger, Furth, and Hilliard (2012) found that subjects *avoid* producing two consecutive words which overlap in onset (“Hannah passed a book to the child” is produced more often than “Hannah *handed* a book to the child”). Since this effect is in the opposite direction of Rapp & Samuel (2002), who used rhyme-related primes, Jaeger et al. conclude that onsets and rhymes produce different priming effects on production. Further research will be needed to determine the nature of onset vs. rhyme effects on lexical access in spoken word production.

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Finally, the Mismatch primes were not controlled for whether the phonologically matched syllables shared morpheme boundaries with the target. For example, the syllable "bal" is morpheme-initial in both "balcony" and "unbalanced", but "unbalanced" was used as a Mismatch Position prime for "balcony". It is possible that shared morpheme boundaries could be treated as a "position match" despite the fact that the word position of the shared syllable between the prime and the target mismatched. A review of the stimuli used in both Experiments 1 and 2 indicated that there were too few stimuli to examine whether morpheme position played any role in the results of the current experiments. It would be of interest in future research to examine the extent to which morpheme boundaries do or do not influence lexical selection processes.

In conclusion, Experiments 1 and 2 show that activation of phonological information influences lexical access, and that this influence is not sensitive to the word position and phonetic realization of the prime-target overlap. We interpret these results as supporting the existence of abstract phonological representations in the spoken word production network.

Acknowledgments

This research was supported in part by NIH Grant RO1 DC006220 from the National Institute on Deafness and Other Communication Disorders. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute on Deafness.

Appendix

Appendix A

Experimental stimuli for Experiment 1.

Target		Match			Mismatch	
abacus	abdicate	sabotage	hibiscus	diabolize	battalion	cassava
abduction	obliterate	conductive	conversation	pliable	ductility	instructional
accelerate	acoustic	outselling	recuperate	elegiac	cellular	exhilarated
adolescent	celestial	subjacent	admonition	lessening	adjudicate	absentee
albino	allopathic	unbinding	piano	hypoallergenic	binary	noticing
alchemy	algebra	sycamore	salami	geniality	comprise	meteor
ambulance	amateur	phobially	opulence	iambic	adverbial	balancing
amputate	ambient	reputable	acetate	Preamble	putative	vegetative
architect	Arkansas	nicotine	protect	anarchical	catalysis	tectonic
audible	odyssey	wildebeest	cannibal	periodic	debase	Belinda
audience	oddity	odious	brilliance	idiotic	deify	leniency
autopsy	ottoman	ectopic	queasy	patriotic	topical	seepage
balcony	balustrade	reconcile	villainy	unbalanced	contagion	cranium
battery	battlement	guttural	actuary	sabbatical	tureen	realigning
biology	biennial	vitriolic	apogee	alibi	Oliver	geocentric
calendar	calcium	Valentine	plunder	incalculable	stolen	derive
calorie	calcified	Polaroid	ornery	recalcitrant	Lorraine	reapply
Canada	cantaloupe	unadorned	Linda	bicameral	arachnid	delicious
cartographer	carcinogen	plastogamy	camphor	incarnation	toggling	forensic

Target		**Match**			**Mismatch**	
chandelier	shantytown	debris	cavalier	scrimshander	delineate	leering
cigarette	signaling	invigorate	minaret	insignia	gorilla	reticence
circumference	sorority	encumbent	conference	exacerbate	compass	inferencing
collision	colloquial	elicit	disillusion	accolade	listener	occasionally
composer	compunction	symposium	accuser	cucumber	predispose	misery
congregation	confidential	sagacious	discretion	Yukon	geisha	devotional
continent	malignant	consecrate	detonate	reconnaissance	tenacious	pregnantly
conversion	conception	reversal	circumcision	drunkenly	verbiage	divisional
Democrat	demagogue	stomachache	plutocrat	pandemic	hammock	hippocratic
eavesdropper	evenly	name-dropping	caliper	naively	raindrop	parental
epidermis	episodic	hypodermic	litmus	narcolepsy	dervishes	mosquito
evolution	evidential	polluted	narration	whoever	lucrative	cautionary
excavate	extradite	Muscovite	inactivate	inexpert	cavort	innovated
graduate	gradually	extrajudicial	asphyxiate	Leningrad	judicious	creativity
gravity	gratifying	covetous	obscenity	ingratitude	vituperate	tiara
hibernate	hyacinth	tuberose	dominate	Ohio	barometer	natal
hurricane	Hercules	oracle	cocaine	rehearsal	raccoon	canine
hypochondriac	hybridization	reconstitute	aphrodisiac	dehydration	confiscated	academic
innocent	instigate	menacing	adjacent	reinsulate	necessity	accented
insomnia	insipidly	ensemble	gardenia	reinstate	somnolence	perennially
interrogate	inversion	Ontario	litigate	ruination	terrify	obligating
intersection	instrument	dissecting	malefaction	uninjured	secretary	actionless
intestine	indefinite	contestable	simpleton	reincarnate	tessellate	tenacity
journalist	Germany	monologue	nihilist	adjourn	provisional	illustrate
Jupiter	julep	serendipity	adulter	rejuvenate	carpet	loitering
kimono	chameleon	ammonia	Milano	predicament	moaning	notational
literate	litany	flatterer	conglomerate	paralytic	commenter	retaliate
magnetic	magnolia	Connecticut	traumatic	demagnify	networking	vertical
marinade	marathon	quarantine	lemonade	intermarry	barren	tornado
mutiny	mutilate	tetanus	calumny	permuted	tonight	Neolithic
nostalgia	nestorian	italic	hydrangea	monastery	talisman	Japan
nucleus	nutrient	dry-cleaner	euphonious	connubial	Cleopatra	assertive
papyrus	papoose	inspiring	vigorous	hippopotamus	pirate	responsive
passenger	pasteurize	dissonant	conjure	capacity	waxen	marjoram
pentagon	pendulum	autograph	foregone	appendix	together	goner
pharmacy	farmstead	enormously	delicacy	safari	misogynist	siesta
photosynthesis	focused	exscinded	colossus	xenophobic	syndrome	sustaining
president	presbyter	supposedly	Occident	oppressive	stanza	dentition
principal	princess	disappear	Episcopal	misprinted	suppressed	impolite
prohibition	procreate	ambitious	vacation	opprobrium	bishop	rational
reception	receding	acceptance	adoption	terraces	scepter	optional
recipe	respirate	municipal	teepee	arrested	suppressible	peony

Target		Match			Mismatch	
referee	reformation	aphorism	jamboree	irreverent	ferocious	Eureka
repellent	rapacious	compelling	fraudulent	parapet	pelican	voluntary
reunion	reelect	biuniqueness	Pennsylvanian	creamery	opinionated	unicycle
rhetorical	retention	notorious	mechanical	conspirator	torturous	calligraphy
singular	single-handed	ambiguous	tutelar	asynchronous	argue	tolerant
studio	stooping	ideology	pistachio	festooning	de-icer	oasis
submarine	substituted	glamorize	wolverine	resubjugate	miraculous	ballerina
synonyms	synapse	pregnancy	platinum	vicinity	vernon	Namibia
veteran	veterinary	trajectory	heron	inveterate	seismometer	occurrences
volunteer	voluble	islander	racketeer	convolving	watermelon	teary-eyed
vulnerable	vulcanizing	generate	symbol	divulging	milliner	ballistic

Appendix

Appendix B

Experimental stimuli for Experiment 2.

Target		Match			Mismatch Position	
abacus	abdicate	sabotage	hibiscus	diabolize	battalion	focusing
abduction	abhor	conductive	conversation	reabsorb	duckling	commissioner
accelerate	accede	outselling	recuperate	elegiac	cellular	irately
adolescent	additive	celestial	subjacent	triad	convalesce	complacently
albino	allopathic	unbinding	piano	hypoallergenic	binary	Nova Scotia
allergy	albatross	cutlery	psychology	joviality	controller	geometry
ambulance	amateur	phobially	opulence	iambic	adverbial	balancing
amputate	ambient	reputation	rotate	Preamble	disrepute	unstately
architect	Arkansas	nicotine	protect	anarchical	certificate	tectonic
audience	oddity	odious	brilliance	theodicy	malady	expediency
autopsy	autumnal	ectopic	bossy	megawatt	housetop	seeker
balcony	ballast	buccaneer	villainy	unbalanced	outspoken	cranium
battery	battlement	guttural	actuary	sabbatical	diameter	realigning
biology	biennial	alcoholic	apogee	alibi	Oliver	geocentric
calendar	calcium	silences	plunder	incalculable	stolen	derive
calorie	calcified	Polaroid	ornery	recalcitrant	Lorraine	reapply
cameo	camouflage	bohemian	leo	bicameral	mediate	geodesic
cartographer	carcinogen	plastogamy	transfer	incarcerate	toggling	forensic
cigarette	signaling	kangaroo	minaret	insignia	gorilla	retina
circumference	serenity	incumbent	conference	exacerbate	cumbersome	inferencing
collision	colloquial	elicit	illusion	broccoli	endless	occasionally
composer	compunction	opposable	accuser	miscommunicate	poses	misery
congregation	concrete	sagacious	discretion	incongruous	gaiety	devotional
continent	conjugate	latency	malignant	anaconda	bitten	pregnantly
conversion	confetti	reversal	circumcision	disconnect	verbiage	divisional

Target		**Match**			**Mismatch Position**	
counterfeit	countenance	interstate	discomfit	accountable	enter	fitness
decagon	decadent	recognize	paragon	ambidextrous	kaput	gondolier
ellipsis	electric	apocalyptic	Pegasus	apparel	lipreader	Narcissism
finale	finesse	analogy	actually	definite	Nalgene	kiloliter
graduate	graphite	nonjudicial	asphyxiate	telegraphic	judicious	sedately
gravity	gratifying	covetous	obscenity	ingratitude	velvet	committeemen
hibernate	hyacinth	tuberose	dominate	Ohio	barometer	innately
hurricane	Hercules	oracle	cocaine	rehearsal	euphoric	canine
hypochondriac	hybridization	reconstitute	zodiac	dehydration	confiscated	accident
innocent	insect	dinosaur	adjacent	reinsulated	necessity	absently
insomnia	insipidly	ensemble	gardenia	reinstate	somber	neoplasm
insurance	interment	assuredly	severance	reinvite	sherbet	tolerances
interrogate	inversion	Ontario	litigate	ruination	terrify	gateway
intersection	instrument	dissecting	malefaction	uninjured	secretarial	actionless
interview	intellect	tottering	purview	reintegrate	encounter	televiewer
intestine	indefinite	contestable	captain	reinstall	tessellate	obstinate
journalist	Germany	analyze	nihilist	adjourn	provisional	philistine
Jupiter	julep	serendipity	pentameter	rejuvenate	carpet	loitering
literate	litigate	flatterer	conglomerate	paralytic	auditor	separately
magnetic	magnolia	clarinetist	traumatic	demagnify	nettling	vertical
marinade	marathon	quarantine	lemonade	intermarry	barren	unaided
metronome	metric	extrovert	garden gnome	symmetrical	electrolyte	misnomer
military	millionaire	posterity	cannery	familiar	Terrence	reanimate
mutiny	mutant	tetanus	detainee	commute	curtain	Neolithic
nucleus	nutrient	dry-cleaner	euphonious	connubial	Cleopatra	assertive
passenger	pasteurize	dissonant	conjure	capacity	waxen	conjuring
pharmacy	farmstead	thermostat	delicacy	safari	infamous	siesta
photosynthesis	focused	exscinded	colossus	xenophobic	Cynthia	systematic
potpourri	poetize	chaperon	debris	apropos	juniper	regal
poverty	populist	feverish	literati	hypocrisy	clever	protean
president	predicate	supposedly	rodent	supremacy	stanza	imprudently
principal	princess	participate	Episcopal	misprinted	gossip	impolite
prohibition	procreate	ambitious	vacation	opprobrium	bishop	rational
recipe	respirate	municipal	teepee	arrested	supplanted	timepieces
referee	reformation	aphorism	jamboree	hereditary	ferocious	Eureka
reunion	reelect	immunity	Pennsylvanian	armory	unicycle	opinionated
rhetorical	retention	notorious	mechanical	heretic	torturous	alkali
submarine	substituted	tamarind	wolverine	resubjugate	marooning	ballerina
summary	sumptuous	numeral	owlery	consumption	meridian	rearrange
synonym	synapse	pregnancy	denim	vicinity	Vernon	animal
veteran	vetted	catering	heron	Helvetica	seismometer	occurrences
volunteer	voluble	colonize	racketeer	convolving	watermelon	teary-eyed

Target		Match			Mismatch Position	
vulnerable	vulcanizing	generate	symbol	divulging	milliner	ballistic

Target		Mismatch Phonetics	
abacus	diabolic	banana	cassava
abduction	diabetes	ductility	shindig
accelerate	reactive	celebration	serrated
adolescent	inadmissible	lessening	concentration
albino	dial	binoculars	noticing
allergy	causally	lurking	genus
ambulance	disambiguate	proverbial	Lansing
amputate	overambitious	putative	agitated
architect	matriarch	catastrophe	detected
audience	periodicity	dehumanize	truancy
autopsy	patriotic	topography	seeded
balcony	counterbalance	contagion	needle
battery	wombat	turban	rehab
biology	unbiased	alcohol	genius
calendar	localize	lending	moderate
calorie	local	loris	regal
cameo	encamping	mediocrity	deodorant
cartographer	incarnation	cryptogram	furry
cigarette	insignificant	vinegar	reticence
circumference	disservice	income	conferencing
collision	semicolon	listener	revisionist
composer	uncommon	predispose	reserving
congregation	Yukon	gaily	sensational
continent	misconstrue	tenacious	tenantry
conversion	inconsequent	shiver	delusional
counterfeit	recount	altar	befitting
decagon	indexes	capacity	agony
ellipsis	citadel	tulip	abscissa
finale	infinity	functional	leadership
graduate	pomegranate	jubilant	creativity
gravity	programmer	vituperate	tiara
hibernate	knee-high	Berkeley	natal
hurricane	cowherder	rickety	archangel
hypochondriac	Shanghai	reconnect	accredit
innocent	reinvest	bonus	accented
insomnia	disinclined	sombrero	perennially
insurance	evincing	pressure	preferences
interrogate	reincrease	pterodactyl	obligating
intersection	coincide	secretary	relationship
interview	uninvited	terrain	viewfinder

intestine	reincarnate	protest	continue
journalist	sojourner	terminal	enlisting
Jupiter	injudicious	patella	Torino
literate	debilitation	commenter	laboratory
magnetic	Armageddon	networking	antiquity
marinade	remarry	rinsing	tornado
metronome	mimetic	trochaic	binomial
military	similar	terrific	rebate
mutiny	permutation	tonight	kneecap
nucleus	maneuver	Kleenex	acidic
passenger	impassivity	sensitive	juror
pharmacy	dairy farming	masseuse	sequel
photosynthesis	bifocals	syncopation	persistent
potpourri	tempo	peripheral	aerial
poverty	pickpocket	virtuous	tedious
president	impressionistic	visa	dentition
principal	apron	suppressed	politicize
prohibition	approbate	rubbish	stationery
recipe	heiress	sipping	pediatric
referee	irreversible	furnish	rebirth
reunion	arena	uniqueness	leniency
rhetorical	regretful	elector	calligraphy
submarine	insubstantial	marital	careening
summary	opossum	nightmare	retail
synonym	assassin	cannon	nimble
veteran	Corvette	tureen	irony
volunteer	revolution	befallen	materialistic
vulnerable	convolution	nurture	baloney

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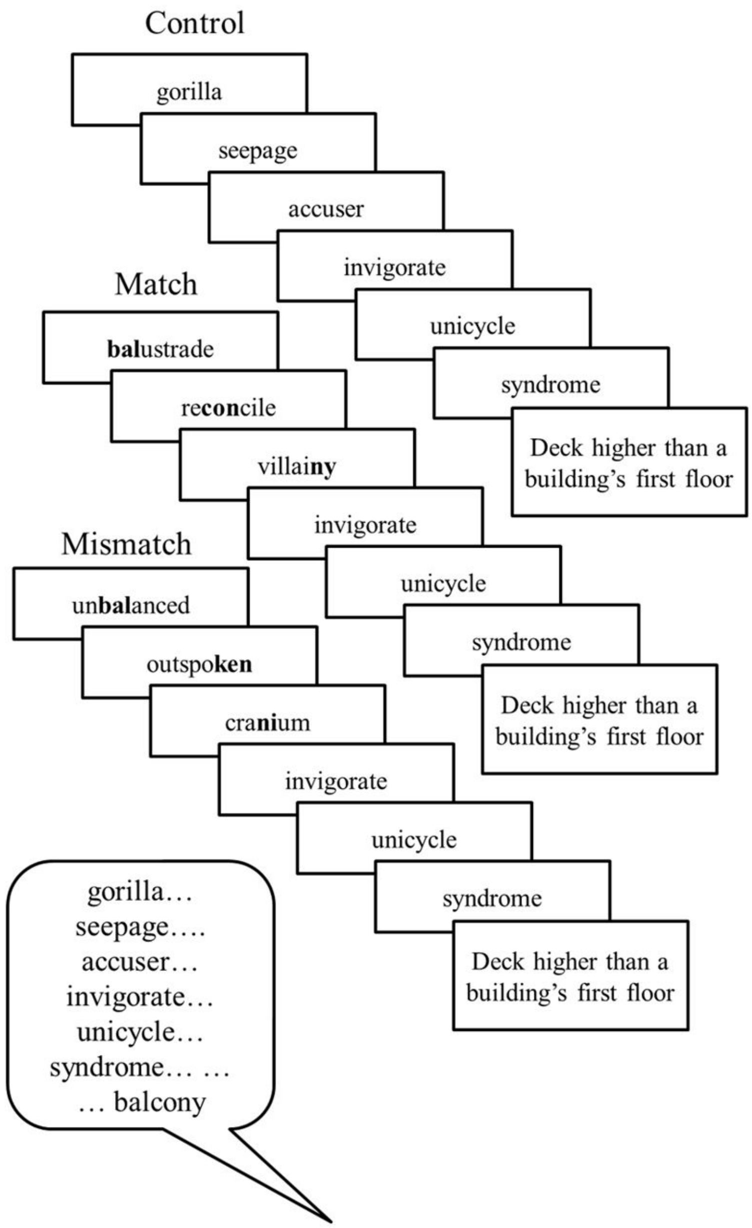


Figure 1.
Experimental Design.

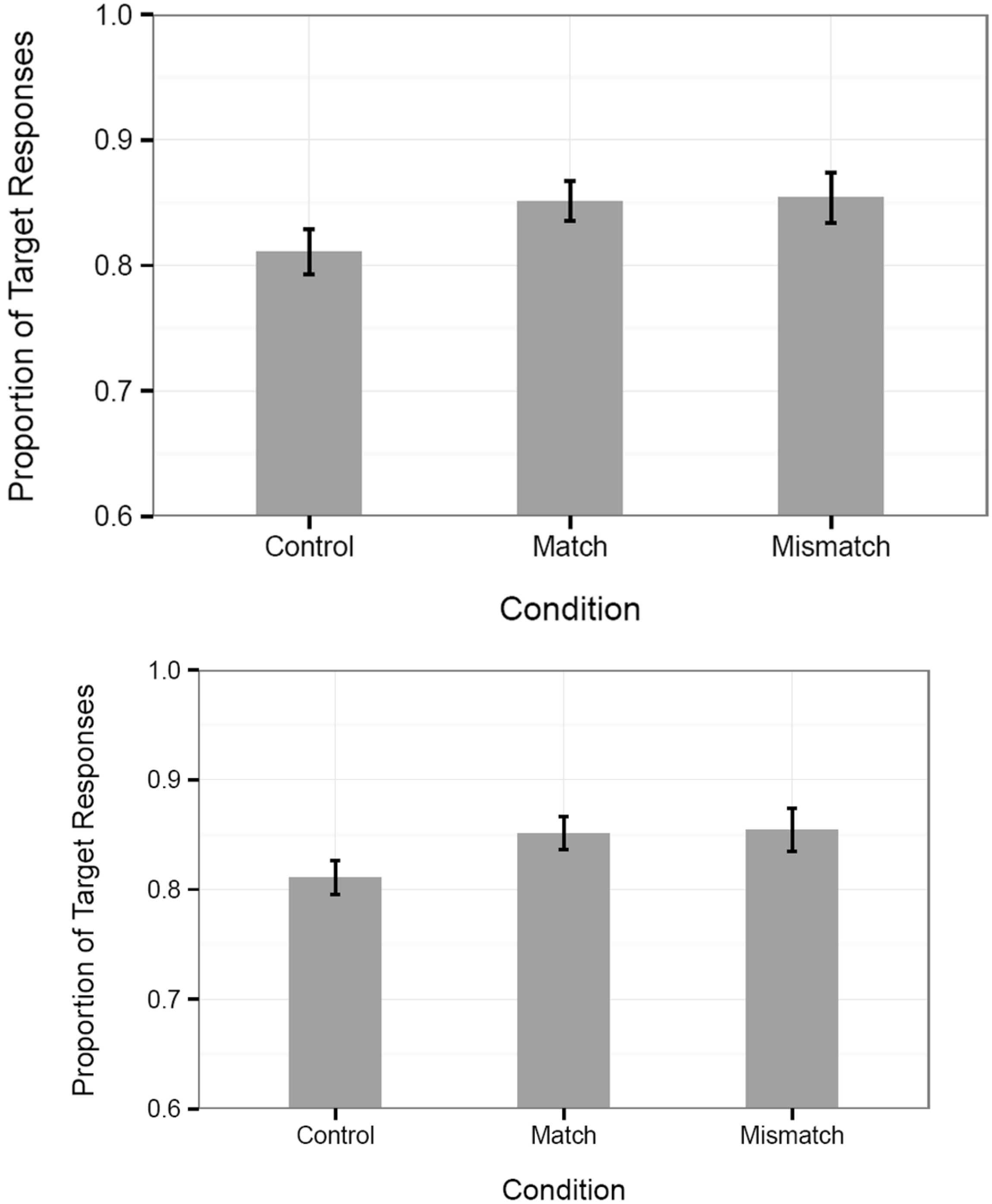


Figure 2.

Proportion of target responses from Experiment 1. a) Within-subject analysis; b) Item analysis.

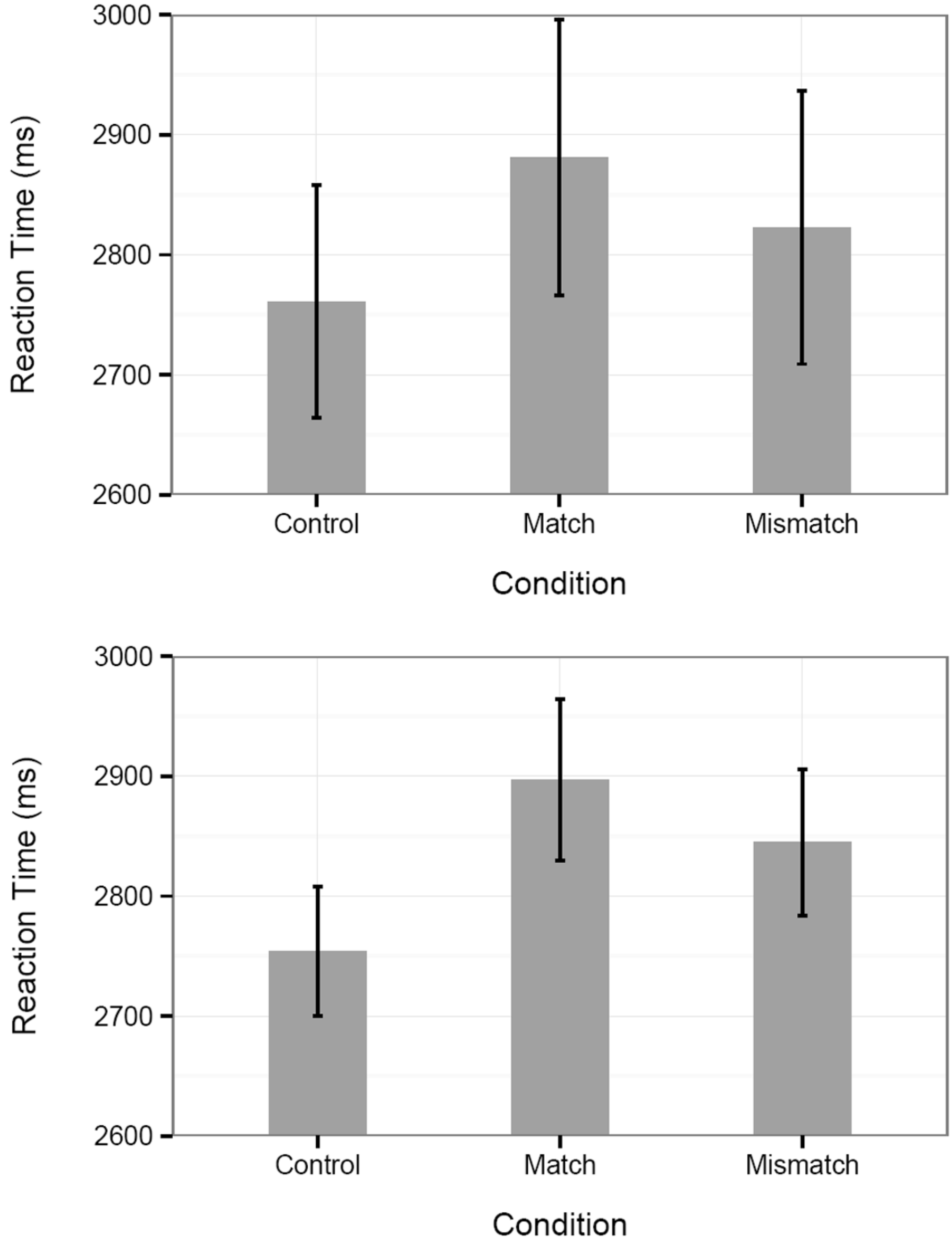
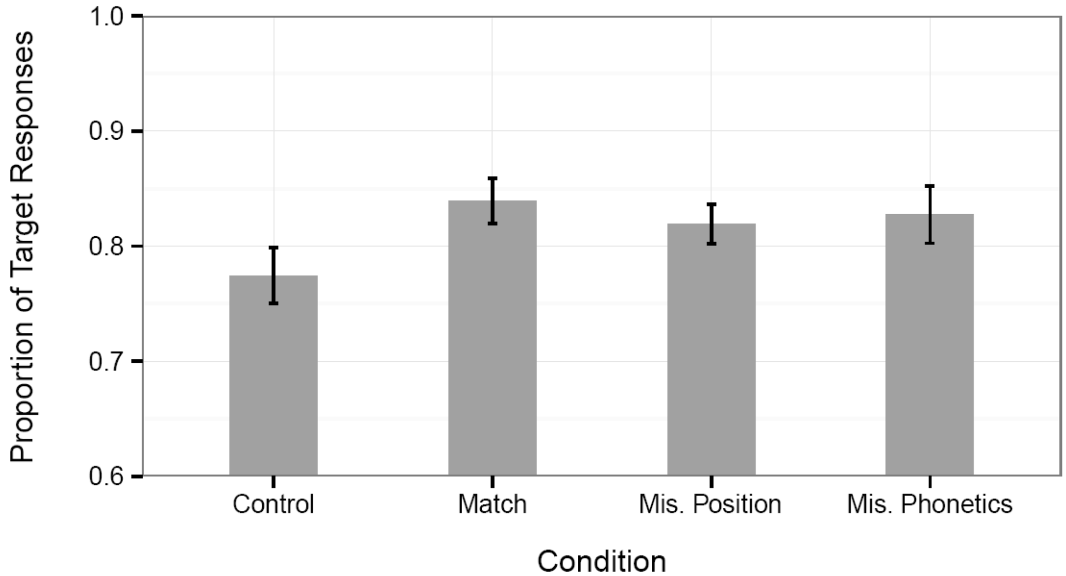


Figure 3.
Reaction times from Experiment 1. a) Within-subject analysis; b) Item analysis.



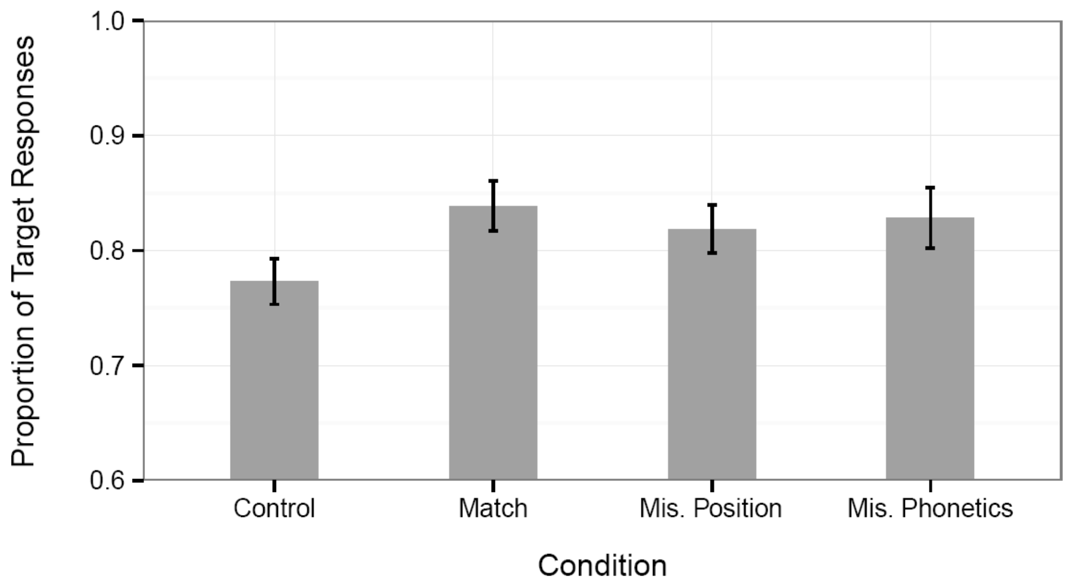


Figure 4.

Proportion of target responses from Experiment 2. a) Within-subject analysis; b) Item analysis.

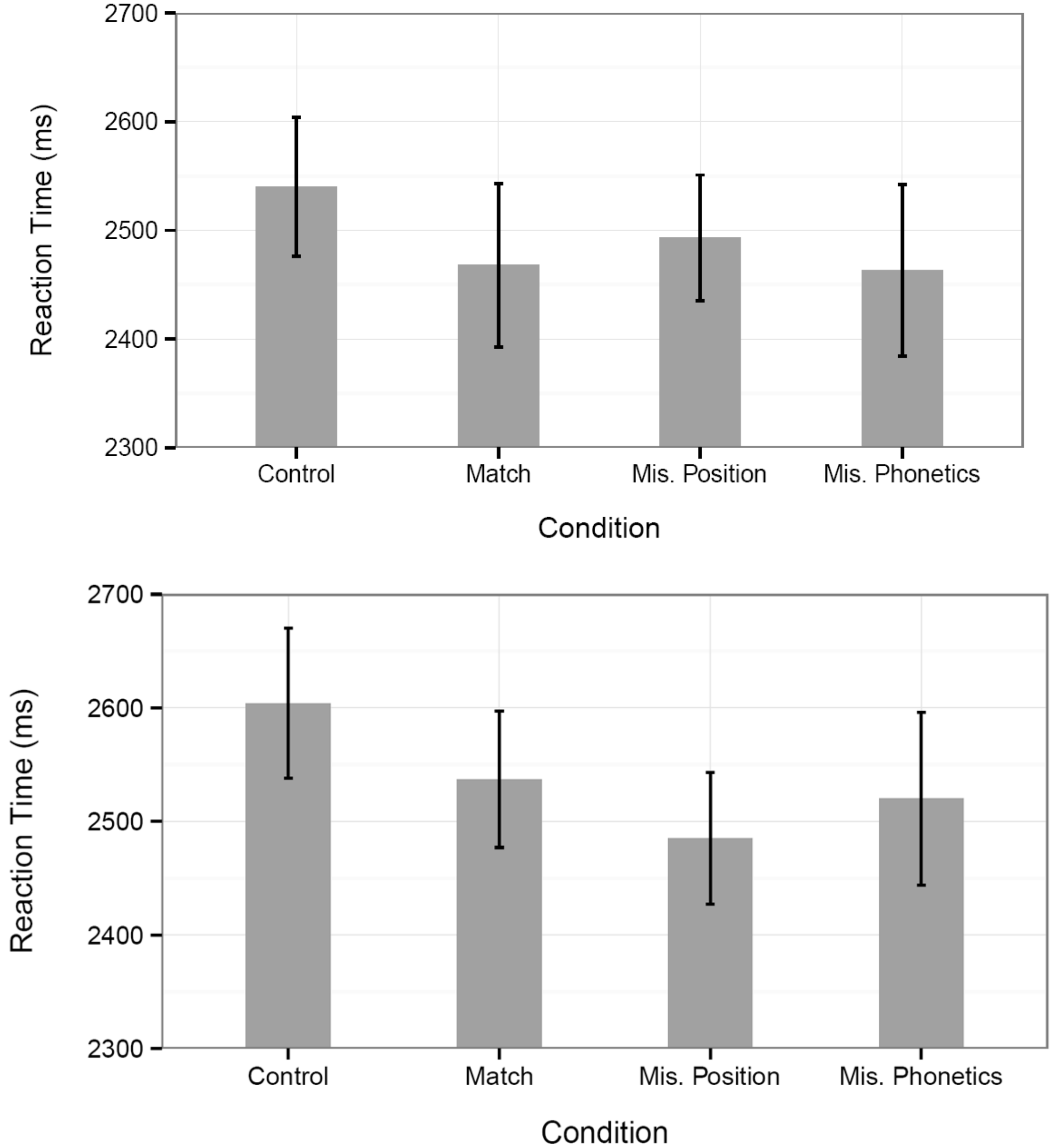


Figure 5.
Reaction times from Experiment 2. a) Within-subject analysis; b) Item analysis.

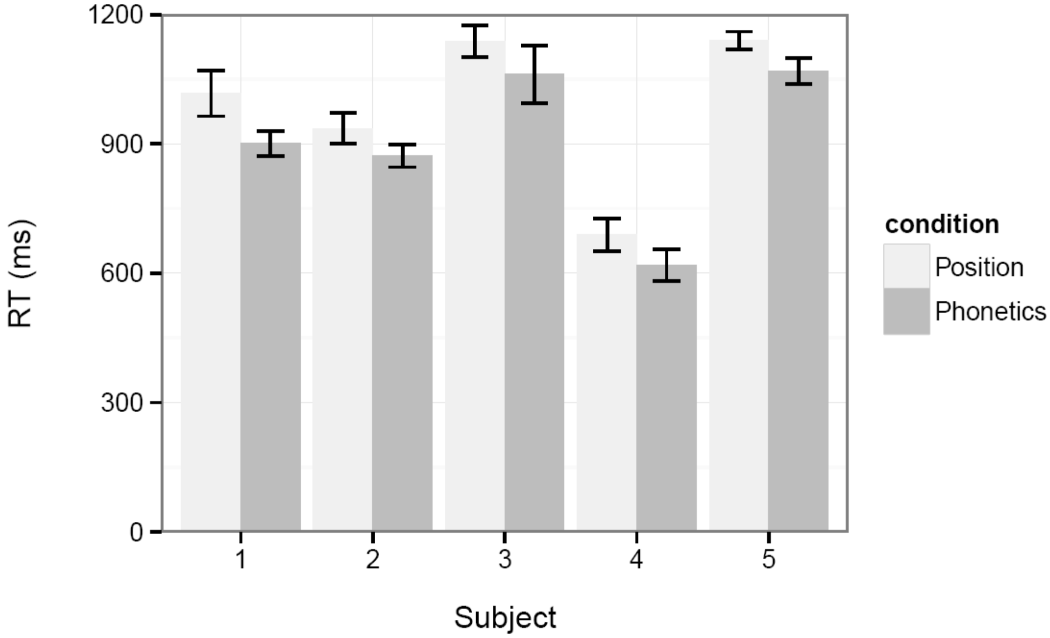


Figure 6.
Speaker identification results for each subject, perceptually comparing the two Mismatch conditions in Experiment 2.

Table 1

Data from Experiment 1: Item analysis. Mean (SE)

	Match	Mismatch	Control
Proportion of correct target responses	**0.851** (0.131)	**0.854** (0.126)	**0.811** (0.166)
Proportion of semantic competitor responses	**0.082** (0.012)	**0.093** (0.012)	**0.118** (0.015)
Proportion of timeouts	**0.044** (0.008)	**0.034** (0.008)	**0.039** (0.009)
Other responses	**0.022** (0.006)	**0.021** (0.006)	**0.033** (0.007)
Reaction time	**2897** (67)	**2845** (61)	**2754** (54)

Table 2

Data from Experiment 2: Item analysis. Mean (SE)

	Match	Mismatched Position	Mismatched Phonetics	Control
Proportion of target responses	**0.839** (0.020)	**0.820** (0.022)	**0.827** (0.021)	**0.775** (0.026)
Proportion of semantic competitor responses	**0.065** (0.013)	**0.081** (0.014)	**0.074** (0.014)	**0.099** (0.014)
Proportion of timeouts	**0.073** (0.014)	**0.080** (0.015)	**0.091** (0.016)	**0.098** (0.018)
Other responses	**0.020** (0.006)	**0.010** (0.005)	**0.011** (0.005)	**0.025** (0.007)
Reaction times	**2537** (66)	**2485** (60)	**2520** (58)	**2605** (76)

Table 3

Summary of Phonetic Changes to Mismatched Phonetics stimuli in Experiment 2.

Phonetic Change	Number of instances
stress	140
vowel quality	40
aspiration	52
/l/-darkening	10
tap/t/release	41
/n/ velarization	4
vowel nasalization	4