Effects of Pragmatic Inference on Phoneme Identification

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Abstract

Although previous research has established that multiple top-down factors guide the identification of sounds during speech processing, the ultimate range of interaction across levels of linguistic structure is still unknown. In a set of experiments, we investigate whether interactive effects emerge between the two most disparate domains: pragmatic inference and acoustic speech perception. We use contexts that trigger pragmatic expectations regarding upcoming coreference (expectations for either *he* or *she*), and, in those contexts, we test listeners' identification of phonetic category boundaries (using words on the /hi/~/ʃi/ continuum). The results indicate that pragmatic inference can indeed alter listeners' identification of phonetic categories.

Keywords: Phonetics, pragmatics, categorical perception, pronoun interpretation, implicit causality

Introduction

There is a growing body of evidence suggesting that language processing requires the integration of multiple sources of linguistic knowledge across multiple levels of linguistic structure. These relevant knowledge sources range from low-level features of the acoustic signal, through lexical and morpho-syntactic properties of words and phrases, up to higher-level semantic and pragmatic inferences about the speaker's intended message (e.g., Ganong 1980 and Pitt 1995 for lexical effects on phoneme perception; Spivey & Tanenhaus 1998 for lexical effects in syntactic processing; and van Berkum, Brown, & Hagoort 1999 for pragmatic effects in syntactic processing, among many others). Occupying the far ends of this spectrum are phonetics and pragmatics. Therefore, we submit that identifying contexts in which comprehenders bring together cues from these two very distinct domains would provide a strong demonstration of the maximum extent of this interactivity.

Our experiments test for interactive effects at the pragmatic-phonetic interface in contexts in which listeners' comprehension of an acoustically ambiguous word might reflect pragmatic biases of the discourse context. To do this, we use words whose interpretation is inherently discourse dependent—namely, personal pronouns. Based on existing pragmatics work on pronoun interpretation, we use contexts in which listeners have been shown to anticipate subsequent reference to a particular referent. We then capitalize on the fact that the English third person pronouns *he* and *she* constitute minimal pairs in order to construct acoustically ambiguous words that vary along a *h~sh* continuum. The results we find attest to the extent of interactive effects that any successful language processing model must capture. The results also contribute to the well-established literature on phoneme identification by broadening the set of known factors that can influence processing.

Modeling Pragmatic Interaction

Interactive approaches to processing are characterized by models "in which lexical, structural (syntactic) and interpretive knowledge sources communicate and interact during processing in an optimally efficient and accurate manner" (Marslen-Wilson & Tyler 1980). Existing work has identified top-down pragmatic effects, i.e. interaction, within syntactic processing, but interactive effects between pragmatic and phonetic information sources have not, to our knowledge, been demonstrated before.

Early work demonstrated the effect of pragmatic factors on other levels of sentence processing, showing that appropriate discourse contexts can eliminate syntactic garden paths (Crain & Steedman 1985; Altmann & Steedman 1988). This work established that comprehenders treat material following a definite NP (*The horse* in *The horse raced past the barn fell*) differently depending on the number of available referents (the number of horses) in the discourse context. These contextual effects have been attributed to a felicity constraint that requires that a definite NP have a unique and identifiable referent—a constraint that encourages comprehenders to interpret post-nominal material (*raced past the barn*) as NP modification rather than a main verb. Referential context has also been shown to yield online effects in syntactic processing (Ni, Crain, & Shankweiler 1996; van Berkum, Brown, & Hagoort 1999; Sedivy 2002). These results lend support to models of incremental processing in which comprehenders have access to pragmatic information before sentence-internal syntactic decisions have been fully resolved. Our work also relies on referential biases, but we push the extent of interactivity further by showing that discourse context can influence the identification of a phonetic category boundary.

Modeling Contextual Effects in Phonetics

Existing work on the factors that influence phoneme identification has established that listeners use more than

just the acoustic signal. The contextual factors that have been shown to have an impact include cues such as lexical status, syntactic category, and semantic congruity. The influence of such contextual factors can be captured both in models that permit top-down contextual information to impact sound perception directly, as in McClelland & Elman's (1986) TRACE model as well as in models in which the perceptual system operates fully independently from other levels of language processing and top-down factors only exert an influence at the point of lexical decision, as in Norris, McQueen, & Cutler's (2000) Merge model. Models like TRACE permit interaction at all levels whereas models like Merge attribute top-down effects to the integration of multiple information sources when a lexical decision is made. We use the term *interactive effects* here to refer to listener responses that reflect biases from information sources at different levels of linguistic structure, but we do not distinguish between the interaction and integration accounts (for discussion of this debate as well as methods for distinguishing the two approaches, see Norris et al. 2000, Magnuson, McMurray, Tanenhaus, & Aslin 2003, and Samuel & Pitt 2003). Our primary goal here is to extend the observed range of top-down effects beyond the previously reported lexical, syntactic, and semantic levels.

Contextual effects based on lexical status were first shown by Ganong (1980) in experiments that established that listeners' phonetic category judgments can be influenced by the lexical status of the stimulus: Ambiguous sounds along the /t/~/d/ continuum are more likely to be reported as /t/ when presented as the onset in a *task~dask* continuum and are more likely to be reported as /d/ when presented as part of a *tash~dash* continuum.

Phonetic category judgments are also sensitive to syntactic context: Acoustically ambiguous words along the *to~the* continuum are more likely be reported as *to* in contexts with a verb, as in *We tried to go*, than in contexts with a noun, as in *We tried the gold* (Isenberg, Walker, & Ryder 1980; see also van Alphen & McQueen 2001)

Furthermore, there is evidence that ambiguous sounds are interpreted differently depending on the semantic congruity of the target word in a particular context: Ambiguous sounds along the *path~bath* continuum are more likely to be reported as */p/* in the context *She likes to jog along the…* and are more likely to be reported as */b/* in the context *She needs hot water for the…*(Miller, Green, & Schermer 1984). Miller et al. report, however, that semantic congruity effects disappear when the task requires listeners to focus only on the target word, rather than on the full sentence frame.

One way of understanding these syntactic and semantic effects is to assume that a particular interpretation of the acoustically ambiguous item is more accessible or more strongly activated given the surrounding lexical items. In other words, lexical items like *go* and *gold* constrain the part of speech of the preceding word. Similarly, contexts that mention *hot* and *water* activate the word *bath*, whereas contexts that mention *jogging* activate *path*. These associations can be said to reflect comprehenders' syntactic knowledge and their mental models of particular events and event participants. As such, these results point to the dynamic integration of information sources ranging from hierarchical syntactic structures to real-world event knowledge. However, these associations may also be attributed to simple co-occurrence frequencies (see Willits, Sussman, & Amato 2008 for a co-occurrence-based account of data that has previously been taken to support highly interactive models). That is, it is possible that these results do not reflect listeners' understanding or parsing of the context in question, but rather reflect statistical frequencies over adjacent words.

The results presented in this paper go beyond this previous work in several important ways. In our contexts, we simultaneously hold constant both the lexical status of our target items and their syntactic category. Furthermore, our target items can be considered semantically neutral in that they are used across semantic contexts and their relationships to other words in the context do not reduce to co-occurrence frequencies.

Our experiments demonstrate that phoneme identification is sensitive to pragmatic inferences about referents in the discourse context and to domain-general causal reasoning. First, Experiment 1 replicates the Ganong effect of phonetic~lexical interaction for the /h/~/ʃ/ continuum. Experiments 2 and 3 use a novel design to test whether listeners' pragmatic expectations can influence phonetic category identification. For the second and third experiments, lexical status is not at issue because all acoustically ambiguous sounds yield legitimate lexical items, allowing us to attribute the effects we observe to interactive effects between pragmatic and phonetic cues.

Experiment 1: Ganong Replication for */hi/~/ʃi/*

In order to establish that the /h/~/ʃ/ continuum is a valid one for assessing phonetic category perception, we first obtained a measure of the effect of lexical status on acoustic perception by replicating the Ganong effect for /h/~/ʃ/. We tested whether listeners would judge the ambiguous onset of a monosyllabic item (e.g., /□ik/) as more /ʃ/-like if the English lexicon contains a word with a /ʃ/- onset (e.g., *sheik*) and lacks a corresponding word with a /h/- onset (**heik, *heek*).

Methods

Participants 35 native English-speaking Northwestern University undergraduates received either $6 or course credit for their participation in the study. A subset of these participants also completed Experiments 2 and 3. Note that this experiment, labeled here as Experiment 1, was always completed as the last part of the experiment session if the session included multiple tasks.

Materials Six pairs of items were created such that each pair consisted of a word and a non-word. The pairs *sheik/*heik*, *sheen/*heen,* and *sheaf/*heaf* were the /ʃ/-

biasing pairs in which the /ʃ/- onset constituted a word. The pairs *heeds/*sheeds, heels/*sheels,* and *heave/*sheave* were the /h/-biasing pairs in which the /h/- onset constituted a word. Onsets ranged from /h/ to /ʃ/ along a 20-step acoustic continuum. Unlike the /t/~/d/ continuum, which can be generated by varying a single acoustic parameter, namely voice onset time, /h/~/ʃ/ is not differentiated by a single simple parameterizable acoustic variable. Therefore, we combined two naturally produced tokens of *he* and *she* at varying intensities (McGuire, 2007; Munson & Coyne, *in press*). The duration of the fricative portion, which may also serve as a cue to differentiate these two items, was the average of the */hi/* and /ʃi/ tokens. Items were constructed such that each of the 6 pairs appeared with each of the 20 /hi/~/ʃi/ steps. Participants heard all items twice.

Procedure Participants listened to the items through headphones while sitting in a sound-attenuating booth. For each item, they were asked to indicate using a button box whether the onset of the item sounded more *h*-like or more *sh*-like on a 4-point scale.

Results and Discussion

As predicted, listeners were more likely to report hearing an initial /ʃ/ for /ʃ/-biasing items (items on the *sheik~heik*, *sheen~heen,* and *sheaf~heaf* continua; mean score=2.9, where 1 is /h/ and 4 is /ʃ/) than for */hi/*-biasing items (items on the *heeds~sheeds, heels~sheels,* and *heave~sheave* continua; mean score=2.4). There was a main effect of lexical status with the data collapsed across steps ($F(1,33)=192.737$, $p<0.001$). The results are shown in Figure 1 with error bars for standard error of the mean.

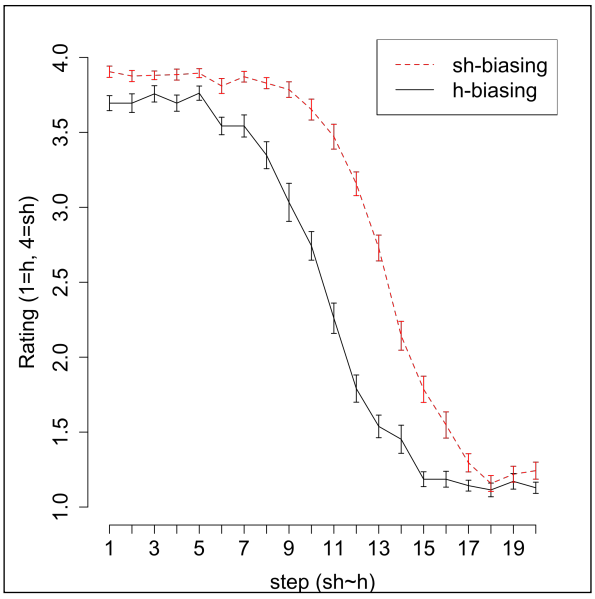

Figure 1: Impact of lexical status on perceived phonetic category for /hi/~/ʃi/ continuum in Experiment 1

The main effect of lexical status replicates the effect originally observed by Ganong for the /t/~/d/ continuum, extending the effect to the /h/~/ʃ/ continuum. Because a subset of the participants had already participated in Experiments 2 and 3 during the experiment session, we also compared performance based on prior experiment participation. There was no difference between participants who had only participated in Experiment 1 and those that had participated in multiple experiments ($F<1$).

Experiment 2: Referential Context

In our first examination of whether listeners' pragmatic knowledge and reasoning influences their phonetic category perception, we used contexts in which all contextually relevant referents were of the same gender in order to see if referential context biased listeners' interpretation of a subsequent acoustically ambiguous pronoun. If listeners do not combine pragmatic and phonetic information in determining phonetic category membership, we would expect to see category assignments based only on the acoustic input of the pronoun, regardless of referential context. On the other hand, if listeners can combine pragmatic and phonetic cues and if pragmatic information is available when listeners are making phonetic category decisions as part of the interpretation of words in full-sentence discourse contexts, we would expect to see category assignments that differ by context.

Methods

Participants 26 native English-speaking Northwestern undergraduates participated. All individuals went also participated in Experiments 1 and 3 during the same session.

Materials 40 sentences were constructed consisting of two clauses connected by *because*. The first clause introduced two individuals of the same gender and the second clause contained an acoustically ambiguous pronoun, as in (1-2).

(1) *he*-biasing context:
Luis reproached Joe because ☐ hadn't done the work**.**

(2) *she*-biasing context:
Joyce helped Sue because ☐ was up against a deadline.

If listeners infer that the discourse context is limited to the two named individuals in the first clause, then the pronoun in the second clause must be linked to an antecedent that is matched for gender. Because the two available referents in the discourse context were of the same gender, the sentences strongly bias the interpretation of the acoustically ambiguous pronouns to *he* in contexts like (1) or *she* in contexts like (2). We normed a total of 20 steps along the /hi/~/ʃi/ continuum (using the /hi/~/ʃi/ component in isolation, not in sentential contexts) to find steps that were centered around the point of maximum ambiguity for listeners. From those 20, we selected a smaller set of 5 steps for testing in order to increase the number of trials at each

data point without repeating items. Each sentence contained a pronoun consisting of one of the 5 /hi/~/ʃi/ steps. We manipulated gender bias within subjects and between items. Participants heard all items once.

Procedure Participants listened to the sentences through headphones while sitting in a sound-attenuating booth. For each item, they were asked to indicate on a button box whether the sentence mentioned *he* or *she*, using a 4-point scale. After each sentence participants were asked a *yes/no* comprehension question based on the sentence's meaning (but not the interpretation of the pronoun) to ensure they were focused on understanding the sentence and not simply focused exclusively on the ambiguous phoneme.

Results and Discussion

Only trials where participants correctly answered the comprehension question were included in the results. As predicted by an interactive account, we found that items with *she*-biasing contexts that contained only female referents yielded higher *she* ratings (mean score=2.3 where 1 is *he* and 4 is *she*) than *he*-biasing contexts that contained only male referents (mean score=1.6). There was a main effect of gender context with the data collapsed across steps ($F(1,26)=37.860$, $p<0.005$). The results appear in Figure 2.

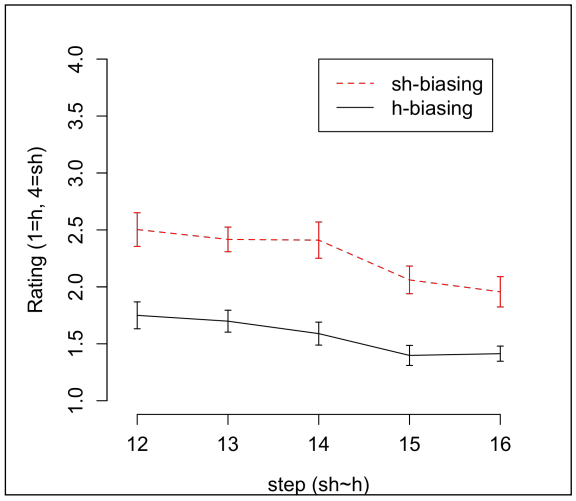

Figure 2: Impact of referential context on perceived phonetic category in Experiment 2

These results support a model of processing in which pragmatic biases are brought to bear on decisions regarding phonetic category membership, at least to the extent that referential context influences listeners' expectations about which individual will be mentioned next.

One question that can be raised regarding Experiment 2 is whether the experiment actually tests listeners' pragmatic reasoning or whether the results can also be explained by semantic neighborhood or co-occurrence effects. Sentences that contain female names may simply be more likely to contain the word *she*, and sentences that contain male names may be more likely to contain the word *he*. Given this concern, Experiment 3 uses contexts in which a female name and a male name are both present. Instead of relying on a single-gender referential context, Experiment 3 uses listeners' pragmatic reasoning about event causality in order to shift co-reference biases.

Experiment 3: Causal Reasoning

In order to construct contexts in which domain-general aspects of pragmatic reasoning might influence sound perception, we used sentences containing verbs from the class of so-called implicit causality verbs (Garvey & Caramazza 1974, *inter alia*). These verbs have been shown to guide listeners' coreference expectations by describing events in which one participant (either the subject or object, depending on the verb) is implicated as central to the event's cause and is thus likely to be re-mentioned in a subsequent *because* clause.

Methods

Participants 26 native English-speaking Northwestern University undergraduates participated. All individuals also participated in Experiments 1 & 2 during the same session. This experiment was completed as the first task.

Materials 40 sentences were constructed consisting of two clauses connected by *because*. The first clause introduced two individuals of opposite gender and an implicit causality verb; the second clause contained an acoustically ambiguous pronoun. Items were balanced for implicit-causality bias (subject preference vs. object preference) and the position of the male and female names (subject vs. object), as in (3-6).

(3) *she*-biasing context, object verb bias
Luis reproached **Heidi** because ☐ was getting grouchy.

(4) *he*-biasing context, object verb bias
Joyce helped **Steve** because ☐ was working on the same project.

(5) *she*-biasing context, subject verb bias
Abigail annoyed Bruce because ☐ was in a bad mood.

(6) *he*-biasing context, subject verb bias
Tyler deceived Sue because ☐ couldn't handle a conversation about adultery.

Each sentence contained one acoustically ambiguous pronoun (taken from the 5 steps on the /hi/~/ʃi/ continuum that were normed for the Experiment 2 materials). Participants heard all items once. In order to ensure that any measured effect was due to the pragmatic biases of the IC verbs and not the plausibility of the sentence continuations (e.g. *he/she was getting grouchy*), we normed the sentences and confirmed that both *he* and *she* versions were judged to be significantly more plausible than a set of implausible

passages ($F(1,11)=770.95$, $p<0.001$, with 12 subjects who did not participate in Experiments 1, 2, or 3).

Procedure The procedure was the same as in Experiment 2.

Results and Discussion

Only trials in which the comprehension question was answered correctly were included in the results. As predicted, we found that *she*-biasing contexts yielded higher *she* ratings (mean score=2.5) than *he*-biasing contexts (mean score=2.0). There was a main effect of gender context with the data collapsed across steps and across verb types ($F(1,26)=18.738$, $p<0.001$). The results appear in Figure 3.

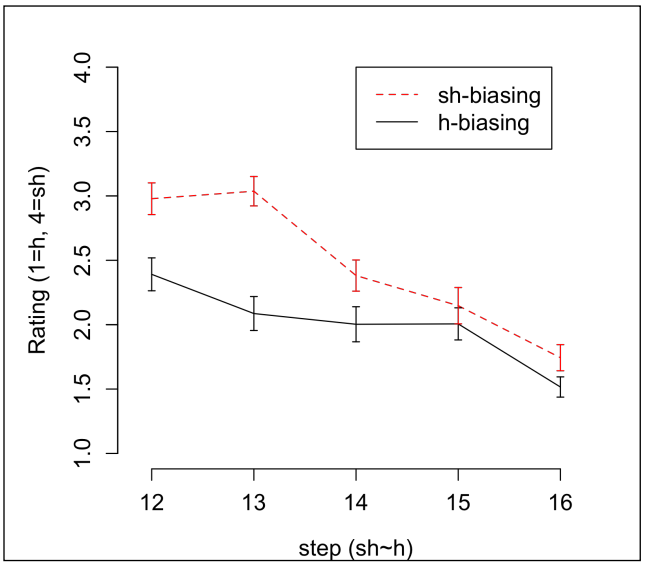

Figure 3: Impact of referential context on perceived phonetic category in Experiment 3

These results support a model of language in which listeners' pragmatic reasoning regarding who is likely to be implicated as the cause of an event influences their phonetic category decisions.

General Discussion

As we described in the introduction, a body of accumulating evidence points to the integration of multiple information sources during language processing. The results presented here suggest that the range of interacting cues spans the conceivable range of linguistic information sources and that phonetic information interacts with high-level causal inferencing about events, event participants, and the likelihood of co-reference across clauses in a discourse.

Our results are in keeping with work showing that the larger discourse context can influence language processing at lower levels. Furthermore, our results suggest that current processing models—be they interactive or integrative—which combine multiple cues from multiple linguistic domains must be refined and better articulated to capture the range of interactivity shown here.

Existing models of phoneme identification currently account for contextual effects such as the semantic congruity effect in one of two ways. Highly interactive models permit direct interaction between acoustic cues, the lexicon, and contextual cues (contextual cues broadly construed, e.g. visual cues, speaker information, acoustic context) such that top-down biases can influence the perceptual system itself (Goldinger 1996; Johnson 1997; Luce & Pisoni 1998; McClelland & Elman 1985). On the other hand, integrative models have been proposed that specify the point of lexical decision as the stage at which listeners combine higher-level information sources with lower-level phonetic cues (Norris et al. 2000). Both types of models could in principle be adapted to account for our results, so long as the range of contextual cues is not restricted to lexical or co-occurrence-based input. For interactive models, an important question is whether pragmatic information is integrated directly into the speech perception process, adding an additional set of non-acoustic cues into the lexical decision process, or whether pragmatic context yields an expectation for a particular continuation, which in turn makes the perceptual process more sensitive to certain acoustic cues. For models that rely on post-perceptual integration of information, however, context serves as a check on an encapsulated perception process; for those models, our results show that pragmatic biases can act as relevant constraints, in addition to other biases that are introduced by lexicality, syntax, or semantics. The difference in effect size between Experiments 2 and 3 may point to differences in the timecourse and strength of such biases.

Just as existing models of phoneme identification could in principle be extended to include higher-level top-down biases, another option for modeling our results would be to adapt existing sentence processing models to capture effects at lower levels of processing. Existing constraint-based sentence processing models have up until now primarily targeted syntactic processes not phoneme decisions (MacDonald 1994; Jurafsky 1996; Spivey & Tanenhaus 1998; McRae, Spivey-Knowlton, & Tanenhaus 1998; Levy 2008, among others). These models—crucially their architectures for integrating multiple cues—could be adapted to fit our data by incorporating discourse-based constraints that interact fully with other processing biases, including those generated at the phonetic level. The work described in this paper attests to the importance of a unified approach that models a range of information sources and their influence on each other during processing.

Existing models have thus not fully addressed the question of precisely which linguistic levels show interactive effects and what mechanism would allow phonetic and pragmatic information to be combined. Our results, which present a new type of interaction, help establish the extent of possible interactivity that must be accounted for, though the results also raise questions regarding the exact nature of these interactive effects.

Recent evidence on the neural bases of lexical effects on phonetic perception points towards the interactive approach (Myers & Blumstein, 2008). The contexts used here provide an opportunity to explore whether different processing systems make use of different strategies for incorporating information from different levels. If multiple systems are in operation, it is possible that the levels in closest proximity interact in a more dynamic fashion. By identifying contexts that induce interactive effects at quite disparate linguistic levels, future work can explore whether the timecourse of such effects are attributable to integrative or interactive mechanisms. Future work must address these questions, and the paradigm we have introduced here provides useful contexts for such work precisely because these contexts permit the manipulation of biases that may be active when listeners are interpreting sounds in rich discourse contexts.

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