Assessing Priming for Prosodic Representations: Speaking Rate, Intonational Phrase Boundaries, and Pitch Accenting

Kristen M. Tooley[1], Agnieszka E. Konopka[2], and Duane G. Watson[3]

[1]Texas State University

[2]University of Aberdeen

[3]Vanderbilt University

Corresponding Author:

Kristen Tooley, Ph.D.

601 University Drive

San Marcos, TX 78666

ktooley@txstate.edu

**Abstract**

Recent work in the literature presents a puzzle: some aspects of prosody can be primed in production (e.g., speech rate) while others cannot (e.g., intonational phrase boundaries, or IPBs). Three experiments aimed to replicate these effects and identify the source of this dissociation. Experiment 1 investigated how speaking rate and the presence of an intonational boundary in a prime sentence presented auditorily affect the production of these aspects of prosody in a target sentence presented visually. Analyses of the targets revealed that participants' speaking rate, but not production of boundaries, was affected by the priming manipulation. Experiment 2 verified whether speakers are more sensitive to IPBs when boundaries provide disambiguating information, and replicated Experiment 1 in showing no IPB priming. Experiment 3 tested whether speakers are sensitive to another aspect of prosody – pitch accenting – in a similar paradigm. Again, there was no evidence that this manipulation affected pitch accenting in target sentences. These findings are consistent with earlier research, and suggest that aspects of prosody that are *paralinguistic* (like speaking rate) may be more amenable to priming than *linguistic* aspects of prosody (such as phrase boundaries and pitch accenting).

Keywords: prosody, priming, intonational phrase boundary, speaking rate, pitch accenting

*Priming and Models of Language Processing*

As in most domains of cognitive psychology, understanding the processes that underlie language behaviour is an empirical challenge because these processes cannot be observed directly. Instead, the field relies on analyses of performance in language-oriented tasks to shed light on these processes, and then formulate models of language representation and use. A classic example is the use of priming tasks, which have provided extensive insight into the way language knowledge is stored, activated, and used during comprehension and production (Pickering & Ferreira, 2008). Our previous work (Tooley, Konopka, & Watson, 2014) suggests that, unlike every other level of linguistic representation tested so far, one aspect of prosody – intonational phrase boundaries (IPBs) – is not amenable to priming. A further puzzle is that previous work has suggested that another aspect of prosody – speech rate – is primeable (Jungers, Palmer, & Speer, 2002; Jungers & Hupp, 2009).  In this paper, we first aim to replicate this prosodic priming asymmetry in one experiment; then we investigate priming for IPBs and pitch accenting in two further experiments to assess the similarity of the underlying representations of these aspects of prosody. Below we first discuss the role of priming in language research and the types of inferences made from priming effects. Then we present three studies investigating priming of intonational boundaries, speech rate, and pitch accenting.

*Priming as a Method*

The term *priming* usually refers to a facilitation of a construction/retrieval mechanism that the language user deploys due to recent experience with similar representations.  For example, in *lexical* priming studies, participants are normally faster in lexical decision tasks after exposure to related words (e.g., Meyer & Schvaneveldt, 1971). These findings helped to motivate models of semantic memory (Collins & Quillian, 1970; Collins & Loftus, 1975; see also Gabora, Rosch, &

Aerts, 2008; Rosch, 1975) and lexical ambiguity resolution (e.g., Swinney, 1979), and they paved the way for more specific models of lexical access during comprehension (McClelland, & Elman, 1986; Vigliocco, Vinson, Damian, & Levelt, 2002).

More recently, priming tasks have also been used to investigate complex representations like syntactic structure. Studies of *syntactic priming* show that speakers reuse recently processed structures when producing novel sentences, such as when describing pictured events or completing sentence preambles (Bock, 1986; see Pickering & Ferreira, 2008, for a review). Priming also occurs in dialogue, including alignment of terminology (Brennan & Clark, 1996; Schober & Clark, 1989) and syntactic structures (Branigan, Pickering, & Cleland, 2000) between conversation partners, as well as higher-level representations, like situation models (Reiter & Moore, 2014; Schober, 1993). Such findings helped motivate the Interactive Alignment Model (Garrod & Pickering, 2004), which posits a language mechanism that causes language users to adapt their linguistic representations to those of their conversation partners in order to facilitate communication.

Thus, priming tasks provide a fruitful avenue to study the mental representations and processing of language: the extent to which priming is observed for a specific aspect of language has implications for whether, and how, that information is represented during processing. Recently, priming tasks have also been used to investigate how different aspects of prosody are represented and planned during production (Jungers & Hupp, 2009; Tooley, Konopka, & Watson, 2014). This line of research provides novel and important evidence about the nature of prosodic representations and helps to establish where prosody fits in a process model of language production.

*Priming for Prosodic Representations*

Prosody refers to acoustic aspects of spoken language that are not specific to individual vowels or consonants, but to larger units such as words or phrases in an utterance, such as rhythm, pitch, intonation, and speech rate. *Intonational phrasing* refers to perceptual groupings of words within an utterance. Intonational phrases are separated by intonational phrase boundaries (IPBs), which are perceived as pauses, and can be recognized by a pause in sound energy and/or lengthening of the pre-boundary word and tonal movement at the end of the phrase (see Wagner & Watson, 2010, for a review). How this aspect of prosody is represented and planned during production processes is still unclear. However, if IPBs are a structuring property of spoken language (grouping words together in time) in the same way that syntax is a structuring property of language (grouping words into grammatical phrases), they may be expected to prime in the same way that syntactic structures can be primed.

Yet, our earlier work in this area found no evidence of priming for IPBs (Tooley et al., 2014). We manipulated the presence of a boundary at two syntactic locations in prime sentences that were presented to participants auditorily. Participants repeated the prime sentences, and then silently read and repeated a visually presented target sentence out loud, from memory. In three experiments, participants produced pauses at the primed locations in the prime sentences they repeated, but these effects did not carry over to the target sentences. This was the case whether participants repeated back the prime sentence (Experiment 2) or not (Experiment 3) before receiving the target sentence. These findings are markedly different from priming effects observed at other levels of linguistic representation, including syntax, where experience with a prime sentence reliably affects syntactic choice in a target sentence (e.g., Bock, 1986; Pickering & Branigan, 1998). To our knowledge, intonational boundary production may be the only aspect of linguistic representation reported thus far that is not amenable to priming.

One possible explanation for the lack of IPB priming is that speakers do not create a separate, abstract plan for when and where to produce boundaries in a sentence. Thus, there may be no representation to prime. Instead, boundaries may be triggered by cues from the syntactic and semantic processing stages (see Tooley et al., 2014 for a production model that incorporates this account of IPBs).

While these findings offer an explanation for how one aspect of prosody may be represented during planning, they also present a puzzle. There are a number of reports of robust priming effects for different aspects of prosody. For example, interlocutors' F0 and intensity become more alike over the course of a conversation (de Looze et al., 2014; Levitan, Rivka, & Hirschberg, 2011; Ward & Litman; 2007). This entrainment is linked to real-world behavior. For example, the amount of prosodic convergence that occurs in a conversation can be used to predict positive and negative affect in couples undergoing marriage counselling (Lee et al., 2010). Additional work suggests that prosodic entrainment can interact with the content of the conversation: couples who entrain while discussing a conflict are less likely to resolve that conflict (Weidman, Breen, & Haydon, 2016). Although this line of work shows that there is a strategic or communicative dimension to prosodic entrainment, it also points to the possibility of priming occurring for the underlying prosodic representation.

There is also clear evidence of prosodic priming for *speech rate* in non-conversational tasks that closely resemble traditional priming paradigms (Jungers, Palmer, & Speer, 2002; Jungers & Hupp, 2009). Jungers and Hupp (2009) auditorily presented participants with three prime sentences, spoken at a fast or slow rate, while they viewed a clipart image depicting the meaning of each sentence. Participants were then asked to describe a new target image. The rate of their productions for target sentences depended on the rate of the prime sentences they heard

(target speech rate was faster after fast primes and slower after slow primes). The fact that encountered speech rate does prime speaking rate of later utterances suggests that speech rate may be planned separately from other representations.

If different aspects of prosody share a common type of underlying representation and are planned at a similar stage of processing, then in principle they should be equally primeable. Yet the evidence presented above suggests that this is not the case: unlike speech rate, we have no evidence that IPBs can be primed. We extend this work in the current study by testing whether the same type of linguistic representations underlie three different aspects of prosody: speech rate, intonational boundaries, and pitch accents. We use a priming paradigm again to test whether production of these aspects of prosody persists from one sentence to another.

The goal of Experiment 1 was to verify that the priming asymmetry between speech rate and IPBs exists when investigated within the same experiment. It is unclear from previous research whether speech rate and IPBs share representational forms. There are known interactions between these aspects of prosody (e.g., speakers produce fewer intonational boundaries in fast than slow speech; Gee & Grosjean, 1983; Jun, 1993), but the presence of an interaction does not directly imply that different aspects of prosody share a common type of representation. Thus, assessing priming for speech rate and IPBs in one experiment is critical to eliminate the possibility that differences in participants and methodology across studies produced the observed differences in priming. Next, Experiment 2 verified whether priming for intonational phrase boundaries may occur only when these boundaries have communicative value. Finally, Experiment 3 tested the validity of our conclusions for IPBs by examining priming of an aspect of prosody that has not been investigated previously: pitch accenting. If the lack of priming for IPBs is due to processing constraints or representational constraints on this

specific aspect of prosody, one might expect other aspects of prosody (i.e., pitch accenting) to show priming. However, if both IPBs and pitch accenting are found to be immune to priming manipulations, this supports the claim that not all aspects of prosody are subsumed under the same processing stage.

## Experiment 1

Experiment 1 used a prime-target paradigm to test whether boundary placement and speech rate of prime sentences can influence the production of new target sentences. Participants listened to and immediately repeated back the prime sentences they heard. These sentences either had no intonational phrase boundaries or had a boundary spliced in at a syntactically preferred location. The sentences were then resynthesized to be either 10% faster or 10% slower than the originally recorded speaking rate (i.e., the naturally produced rate of the speaker). Primes were followed by target trials, where speakers silently read a novel sentence and then repeated it aloud from memory. Durational and perceptual measures were used to determine whether participants persisted in producing the speech rate and IPBs that they heard in the primes when producing the target sentences.

**Method**

*Participants*

64 students from the University of Illinois participated for course credit. Participants in all 3 experiments were native speakers of English with normal hearing and normal (or corrected-to-normal) vision.

*Materials*

We used the experimental sentences from Tooley et al. (2014). The experimental set consisted of 40 items: 20 sentences with relative clauses (e.g., *The dolphin that tossed the ball wanted a*

*reward for his trick*) and 20 sentences with main clauses (e.g., *The girl bought new clothes at the mall today*; Appendix A). Two sentences with the same syntactic structure were yoked together to create 20 prime-target pairs (10 main-clause and 10 relative-clause pairs).

To create the boundary manipulation, two versions of each sentence were initially recorded by a native English speaker: one with and one without an IPB at the critical location. The critical boundary location followed the second noun (e.g., *The dolphin that tossed the ball // wanted a reward for his trick*), as the clause boundary and boundary between the noun and verb phrases make this a natural location for a boundary (e.g. Truckenbrodt, 1999; Watson & Gibson, 2004). For the purpose of our analyses, the critical boundary region includes the word immediately preceding the boundary, the boundary itself, and the word after the boundary. All experimental sentences were created by splicing critical regions from recordings of each condition into a neutral carrier sentence that had no prosodic boundaries. This ensured that the prosody of regions that were outside of the critical region did not influence perception of the critical region. This splicing procedure was used to create sentences in the control condition (with no boundaries) as well as the experimental condition (with a boundary at the critical region). On average, sentences with a boundary were approximately 400 ms longer than those with no boundaries. The sentences were then subjected to a rate manipulation using a rate-resynthesizing script in PRAAT that created two sentence versions that were 10% slower and 10% faster than the original sentences respectively.

The boundary manipulation crossed with the rate manipulation yielded four conditions: fast sentences without boundaries, fast sentences with boundaries, slow sentences without boundaries, and slow sentences with boundaries. Both factors were counterbalanced within-participants and within-items, so each participant saw each sentence in only one of these

conditions. Within lists, each participant received 5 items in each of the four conditions. Additionally, each sentence could appear both as a prime and as a target. Thus, we created eight lists of stimuli to counterbalance the four conditions as well as the prime/target status of each sentence (referred to as *Sentence Position* below) on that list. The experimental sentences were arranged such that no more than two items from the same condition followed one another. Targets always immediately followed primes, and three filler sentences intervened between all prime-target pairs.

Filler sentences included a variety of syntactic structures (e.g., cleft constructions, sentences with fronted prepositional phrases, sentences with that-complements, and sentences with fronted temporal phrases). To reduce the salience of the manipulations in the primes, the fillers also varied with respect to IPBs and speaking rates. Roughly, one half of the fillers had one boundary, one quarter had two boundaries, and one quarter had no boundaries. Boundaries were produced naturally by the speaker and did not include any splicing.  Half of the filler sentences were presented at the original recording rate, one quarter were resynthesized to be 10% faster, and one quarter were resynthesized to be 10% slower.

*Procedure*

The procedure used was the same as in Tooley et al.'s (2014) second experiment. Participants were told that they would either hear recorded sentences or read sentences printed on the screen. After either hearing a sentence or silently reading a sentence, their task was repeat the sentence back out loud. If the sentence was presented auditorily, the word *LISTEN* appeared and remained on the screen while the recording played. At sentence offset, the word *REPEAT* appeared on the screen to prompt participants to repeat the sentence. Participants then pressed the spacebar to advance to the next sentence. If the sentence was presented visually (i.e., if it was

printed on the screen), participants first saw the word *READ* for 1 second, followed by the sentence. The sentence remained on the screen for an amount of time equal to 50 milliseconds multiplied by the number of words in the sentence. After that amount of time elapsed, the word *REPEAT* appeared on the screen, prompting participants to repeat the sentence aloud from memory. Participants then pressed the spacebar to advance to the next trial.

The prime sentences were always *listen-and-repeat* trials (as these recordings contained the manipulations), and the target sentences were always *read-and-repeat* trials (so they were prosodically neutral). Roughly half of the filler sentences were randomly assigned to be presented as *listen-and-repeat* trials, and half as *read-and-repeat* trials. The modality of fillers remained constant across all eight lists, and varied throughout the experiment to reduce the predictability of the trial type. The experiment started with a practice block of four *listen-and-repeat* and four *read-and-repeat* sentences, presented in a pseudorandom order.

*Scoring and analyses*

We excluded responses in which participants changed the syntactic structure of the sentence, paused for extended periods of time (average pause time of 1.36 sec. for excluded trials), produced disfluencies at or near the critical sentence region, or produced sentence fragments. Minor wording changes were acceptable. These exclusion criteria left 1131 trials (out of 1280 total trials) for analysis. Participants' boundary productions were assessed in two ways: one coder (the first author) rated whether or not a boundary was discernible in the critical region, and a second coder (the second author) measured the duration of the pre-boundary word through the onset of the first post-boundary word. Total speaking time of each sentence was also measured. Coders were blind to condition in all experiments.

Analyses were carried out in R (R Development Core Team, 2008) using logit mixed

models for the measure of perceived intonational boundaries, and linear mixed effects models for the analyses of word-and-pause durations and total sentence speaking durations (Baayen, Davidson, & Bates, 2008; Jaeger, 2008). Prime Boundary (present vs. absent), Speech Rate (fast vs. slow), and Sentence Position (prime vs. target) were included as mean-centered fixed effects (along with all interactions), and all models estimated random effects for participants and items. In all experiments, the maximal version of the models (warranted by the design) was used unless this resulted in non-convergence. In those cases, random effects were removed based on the size of their variance components (smaller effects were removed first) until the model reached convergence. All effects were considered significant at $\alpha < 0.05$.

## Results and Discussion

*Sentence Speaking Duration*

The *listen-and-repeat* (prime) sentences were spoken faster when the original recording was the fast sentence version, and slower when the original recording was the slow sentence version (Figure 1a). This effect carried over into the *read-and-repeat* (target) sentences (Figure 1b).
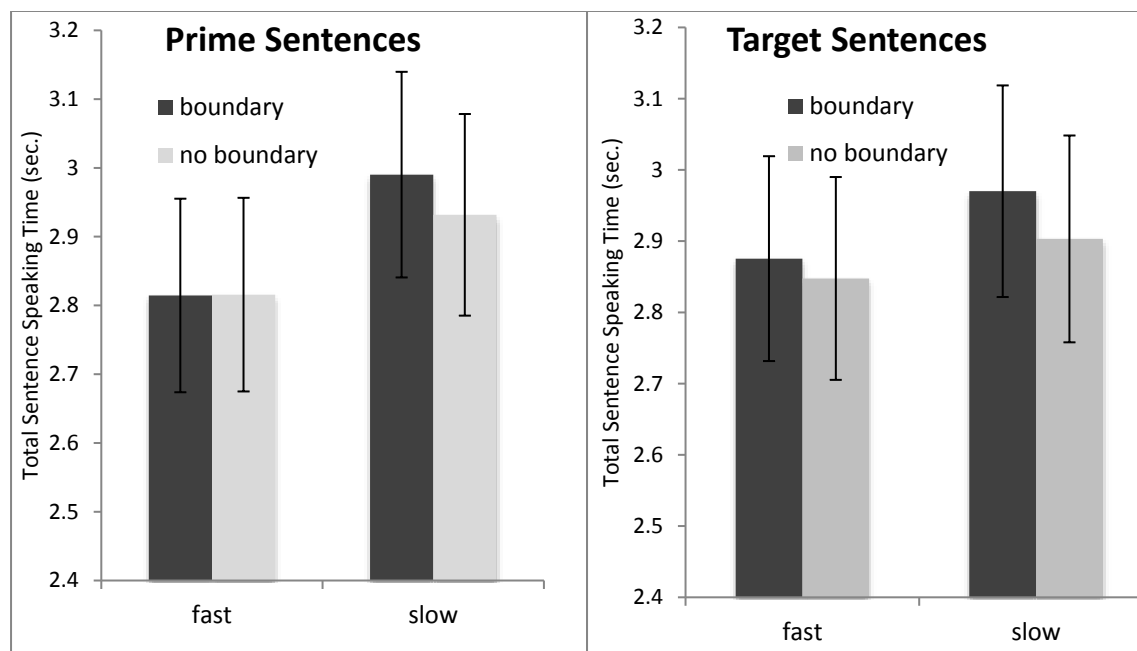
Figure 1: Total Sentence Speaking durations.
Mean total sentence speaking durations for a) prime sentences and b) target sentences across the Boundary and Speaking Rate conditions. Error bars represent 95% confidence intervals.

The analysis of overall speaking times showed significant main effects of Speech Rate and Boundary, and an interaction between Speech Rate and Sentence Position (Table 1). Participants spoke faster and slower after hearing fast and slow prime sentences respectively, but this effect was smaller in the targets than the primes. Participants also spoke more slowly when they heard a prime sentence with a boundary. Follow-up analysis of these effects in target sentences alone revealed a significant effect of prime Speaking Rate, suggesting that the speaking rate of the prime sentences did influence participants' speaking rate in the targets.

Table 1. Analyses of total sentence speaking duration for all sentences (primes and targets). The model includes random by-item and by-participant intercepts, and random by-participant slopes for estimates of Speaking Rate, Boundary, and Sentence Position.

|  | Total Sentence Speaking Duration (sec.) | | |
| --- | --- | --- | --- |
| Predictor | Estimate | St.error | t-value |

| | | | |
|---|---|---|---|
| Intercept | 2.920 | 0.072 | 40.60* |
| Speech Rate | 0.092 | 0.019 | 4.81* |
| Boundary | -0.041 | 0.019 | -2.21* |
| Sentence Position | 0.022 | 0.023 | 0.98 |
| Speech Rate * Boundary | -0.047 | 0.039 | -1.20 |
| Speech Rate * Sentence Position | -0.088 | 0.033 | -2.69* |
| Boundary * Sentence Position | -0.022 | 0.033 | -0.68 |
| Speech Rate * Boundary * Sentence Position | 0.013 | 0.066 | 0.19 |

*Production of Intonational Phrase Boundaries*

The repeated prime sentences were longer and contained a perceived boundary more often when the recorded prime sentence also had a boundary (Figure 2a). This effect however, did not carry over into the *read-and-repeat* (target) sentences (Figure 2b).
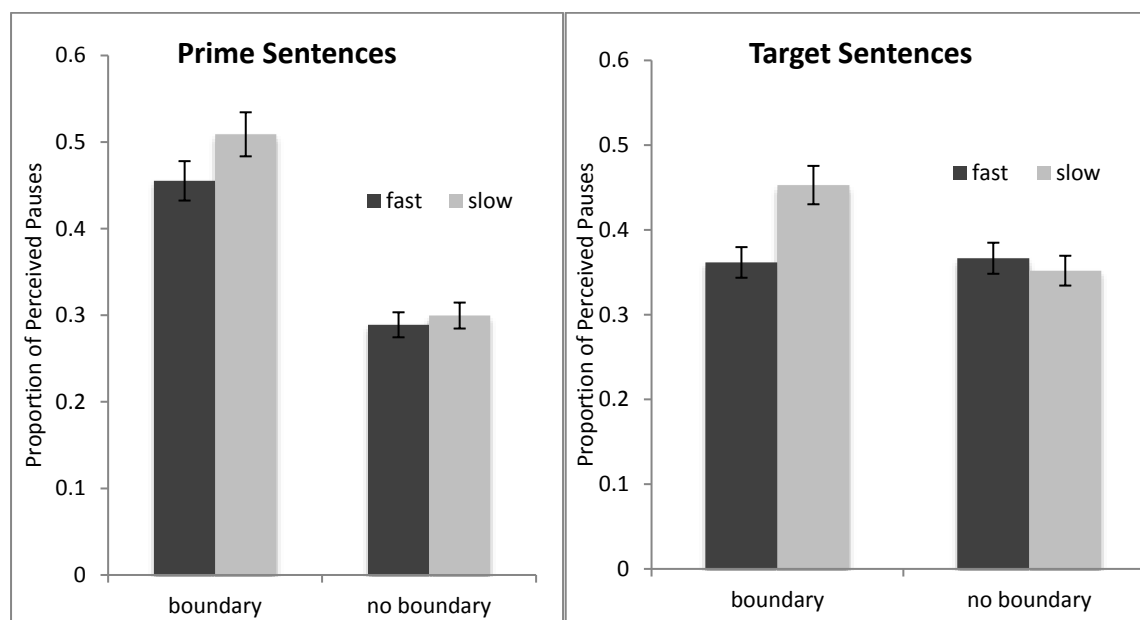


Figure 2: Perceived Pauses.
Proportion of perceived pauses in a) the prime sentences and b) the target sentences across the Boundary and Speaking Rate conditions. Error bars represent 95% confidence intervals.
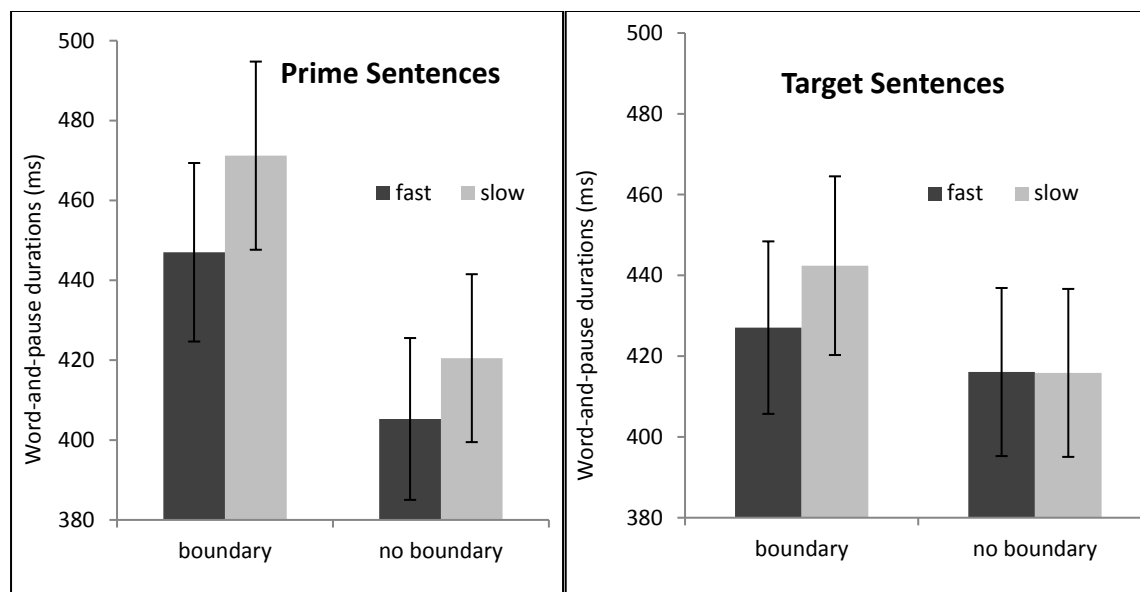
Figure 3: Word-and-Pause Durations.
Mean word-and-pause durations for the critical regions of a) the prime and b) target sentences, broken down by Boundary and Speaking Rate conditions. Error bars represent 95% confidence intervals.

The overall analysis of perceived pauses revealed a main effect of Boundary, a marginal effect of Speaking Rate, and an interaction between Boundary and Sentence Position (Table 2). Participants were slightly more likely to produce a boundary after hearing a slow-rate prime. They also produced boundaries at the critical region more often when they were primed to do so, but this effect depended on Sentence Position: participants reproduced the heard boundaries in prime sentences but did not generalize these boundaries to target sentences. A follow-up analysis restricted to the target sentences confirmed that the effect of Speaking Rate was significant ($p=0.037$) but the effect of Boundary was not ($p=0.10$). In other words, hearing a slower prime increased the chances that participants would produce a boundary in the target, but hearing a boundary in the prime sentence did not.

A similar pattern was observed with word-and-pause durations: word-and-pause durations were longer in sentences produced after hearing slow primes than fast primes and after

hearing primes with boundaries than primes without boundaries (Figure 3). This resulted in a

main effect of Boundary and Speaking Rate but no interaction (Table 2). Importantly, there was

an interaction between Boundary and Sentence Position, as the effect of Boundary on word-and-

pause durations was limited to the repeated prime sentences. There was also a weak interaction

between Speaking Rate and Sentence position, as the effect of Speaking Rate was again limited

to the repeated prime sentences.

Table 2. Analyses of perceived boundary production and word-and-pause durations at the critical
sentence region of all sentences (primes and targets). Model (a) includes random by-participant
and by-item intercepts, and random slopes for estimates of all effects except the interactions
between Rate and Boundary and Rate and Sentence Position. Model (b) includes random by-
participant and by-item intercepts, and additive random slopes for estimates of all effects.

| Predictor | Boundary production | | | Word-and-pause durations | | |
|---|---|---|---|---|---|---|
| | Estimate | S.E. | $z$ | Estimate | S.E. | $T$ |
| *Critical sentence region* | | | | | | |
| Intercept | -0.61 | 0.18 | -3.41* | 434 | 18 | 24.65* |
| Speaking Rate | 0.22 | 0.12 | 1.92† | 12 | 5 | 2.65* |
| Boundary | -0.72 | 0.12 | -6.10* | -34 | 4 | -7.52* |
| Sentence Position | -0.01 | 0.14 | -0.06 | -12 | 6 | -2.07* |
| Speaking Rate * Boundary | -0.24 | 0.20 | -1.21 | -9 | 9 | -.99 |
| Speaking Rate * Sentence Position | 0.11 | 0.20 | 0.56 | -16 | 9 | -1.84† |
| Boundary * Sentence Position | 0.78 | 0.26 | 3.01* | 31 | 9 | 3.54* |
| Speaking Rate * Boundary * Sentence Position | -0.28 | 0.40 | -0.71 | -4 | 17 | -.21 |

* $p<.05$, † $p<.10$

Thus, Experiment 1 replicated previous studies (Jungers et al., 2002; Jungers & Hupp,

2009; Tooley et al., 2014): participants persisted in their use of a faster or slower speaking rate

when the recorded prime sentences also had a faster or slower rate. However, they did not persist in their use of intonational boundaries at the critical target sentence location when the prime sentence contained a boundary at that location. This supports the observation that speaking rate is much more amenable to priming than the production of IPBs. Thus, different types of underlying representations and/or processes may be involved in the production of IPBs and speaking rate.

Interestingly, when participants heard a slow rate prime, their production of the target sentence was more likely to contain a boundary. Likewise, the presence of a boundary in the prime sentence resulted in participants taking longer to produce the target sentence. Participants may have perceived an overall speaking rate that was slower in a prime sentence with a boundary, leading to an overall reduction in speaking rate. This is consistent with earlier work (Lass, 1970) suggesting the perception of speech rate is influenced by the presence of a boundary. Thus, our results are consistent with earlier work showing a relationship between speaking rate and boundary production (e.g., Gee & Grosjean, 1983). Though not the primary focus of this study, this interplay between boundary production and speaking rate can provide novel insight into the relationship between perception and production of prosody.

Naturally, there are limitations to these conclusions. The absence of a priming effect for boundaries does not necessarily mean that no effect was present, as the null finding could reflect an inability to detect such effects in the current paradigm. However, we have consistently found that participants are more likely to reproduce boundaries heard in *prime* sentences (Tooley et al., 2014). This implies that our manipulation is not too weak to influence production and that participants do in fact retain some prosodic information from the prime sentences. Our paradigm was also successful in showing variation in participants' boundary production, but importantly,

this effect was not driven by the boundary priming manipulation.

One plausible alternative for the lack of IPB priming concerns the optionality and information value of the boundaries in the prime sentences. In Experiment 1, as well as in previous studies, the boundaries produced in the primes were not strictly necessary and did not add syntactic or semantic information that might influence comprehension. Thus, they may have been ineffective primes because they did not contribute to participants' interpretation of the sentences. It is therefore plausible that priming may be observed in sentences with more "meaningful" boundaries. We test this possibility in Experiment 2.

## Experiment 2

Previous studies used sentence structures where IPBs are optional and do not add meaningful syntactic or semantic information to the sentence, which may have decreased the saliency of the boundaries. Thus, Experiment 2 used the same prime-target paradigm and the same measures of boundary production as in Experiment 1 but with new, ambiguous sentences where boundaries supported disambiguation. We manipulated the presence of a boundary in the prime sentences (with no manipulation of speech rate). The target sentences were always ambiguous (e.g., *She put the money in the basket on the table*), so their structural interpretations could be influenced by the presence of a boundary in the critical location (i.e., between the phrases *in the basket* and *on the table* in the current example). If priming for IPBs is dependent on the saliency or meaningfulness of those boundaries to the listener, then participants should be more likely to produce a boundary at the critical location in target sentences when they heard a boundary in that location in the primes.

## **Method**

*Participants*

74 Texas State University undergraduates participated for course credit. One participant failed to follow instructions and was excluded from the dataset.

*Materials and design*

The experimental stimuli consisted of a set of 40 sentences that described transfer-of-location events. The sentences were either ambiguous or unambiguous, and either included a boundary at a critical location or did not (examples 2a-2d). In the ambiguous conditions (2a, 2b), the sentences could be interpreted in two ways: someone is putting money in a basket that is on a table or that someone is taking money that was in the basket and putting it on a table. The absence of a boundary (2a) suggests the former interpretation, while a boundary after the word *basket* (2b) suggests the latter.

2a). *She put the money in the basket on the table*. (Ambiguous, No boundary)

2b). *She put the money in the basket // on the table*. (Ambiguous, Boundary)

2c). *She put the money for the basket on the table*. (Unambiguous, No boundary)

2d). *She put the money for the basket // on the table*. (Unambiguous, Boundary)

However, it is also possible that an ambiguous prime with a boundary may reinforce a particular syntactic interpretation, which could then influence the syntactic interpretation (and its appropriate boundary) of the target, via syntactic priming. For example, it is possible that interpreting *in the basket* as a location in sentences 2a and 2b rather than as a modifier would prime a similar interpretation of this phrase in the next target sentence. If so, participants may produce more boundaries at the critical location in the target merely due to persistence of a syntactic frame rather than due to the meaningfulness of the boundary. Thus, in order to be able to interpret effects of the boundary manipulation, we crossed the boundary manipulation with the ambiguity manipulation. Each sentence in the set included two unambiguous versions (sentences

2c and 2d), created by changing a single word, e.g., *money in the basket* and *money for the basket*. Critically, both ambiguous and unambiguous sentences should have the same structural priming effect on an ambiguous target, which will control for effects of syntax.

This design allows us to test for effects of communicativeness on IPB priming. The boundary in sentence 2d occurs in same location as in sentence 2b, but the former boundary provides information that is redundant with the syntax. Comparing these conditions allow us to examine priming in contexts in which IPBs are highly informative syntactically and less syntactically informative. If boundary priming depends on the boundaries' communicative value, effects of boundary meaningfulness should result in stronger priming in the ambiguous than the unambiguous condition.

The boundary manipulation was achieved via the same cross-splicing method as in Experiment 1. Half of the stimuli set (20 sentences) had the critical boundary location after what was the first noun phrase, and half had it after what was the first prepositional phrase in these sentences (see examples 2b and 2d). Thus, critical boundary location was manipulated between-items but within-participants.

Each sentence in the set was yoked to another sentence to form a prime-target pair. The prime sentence was presented in one of the four conditions (as in sentences 2a-2d), and the target sentence was always ambiguous (e.g., *He threw the marble in the bucket in the yard*; target sentences was presented visually again and thus had no prosody). Ambiguity, Boundary, and Sentence Position (prime or target position), were counterbalanced within-participants and within-items to create eight experimental lists. Each participant received 5 items in each of the four conditions obtained by crossing Ambiguity and Boundary. Three filler sentences intervened between each prime-target pair. Filler sentences included relative clause sentences (like the

target sentences from Experiment 1), main clause sentences, and ambiguous sentences such as

*He touched the plant with the leaf*. The fillers also included naturally produced boundaries at

varying syntactic locations.

*Procedure*

The experimental procedure was identical to that in Experiment 1.

*Scoring and analyses*

The boundary scoring procedures were the same as in Experiment 1. Trials where the length of

the critical region was three standard deviations above the mean (i.e., longer than 1.02 seconds)

were eliminated from the dataset. Further, applying the same exclusion criteria as in Experiment

1 resulted in a loss of 13% of the data, leaving 2,576 trials (out of 2,960 possible trials) for

analysis.

The analyses were carried out as in Experiment 1, including the factors Boundary

(present vs. absent), Ambiguity (ambiguous vs. unambiguous prime), and Sentence Position

(prime vs. target), with all interactions.

## **Results and Discussion**

Participants were more likely to produce pauses at the critical region in their repetitions of prime

sentences when the recorded primes contained a boundary (Figure 4a). This effect was stronger

in the repeated primes than in the targets (Figure 4b), and did not vary with prime ambiguity.
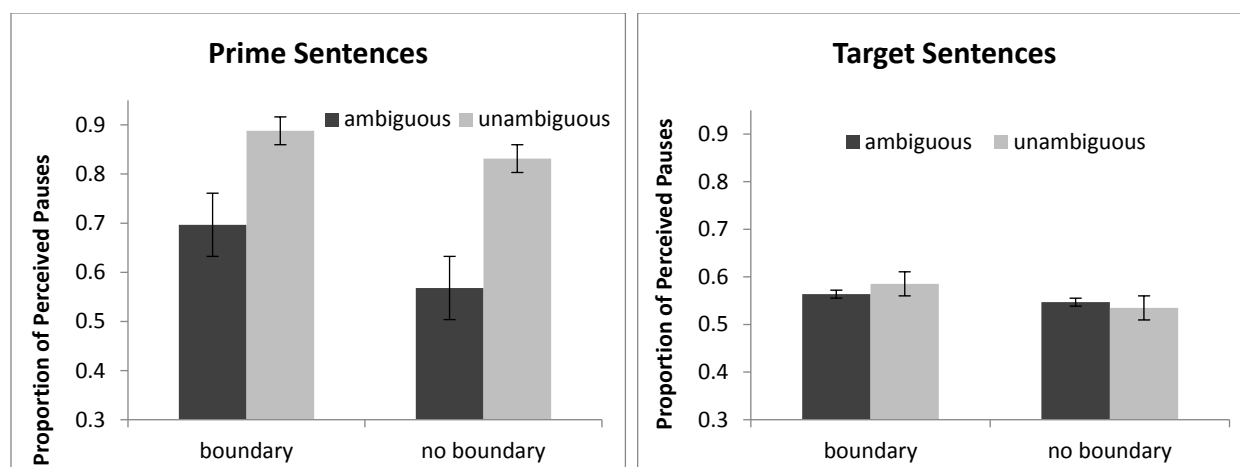
**Prime Sentences**

**Target Sentences**

Figure 4: Perceived Pauses.
Proportion of perceived pauses in the a) prime sentences and b) target sentencesbroken down by the Boundary and Ambiguity conditions. Error bars represent 95% confidence intervals.

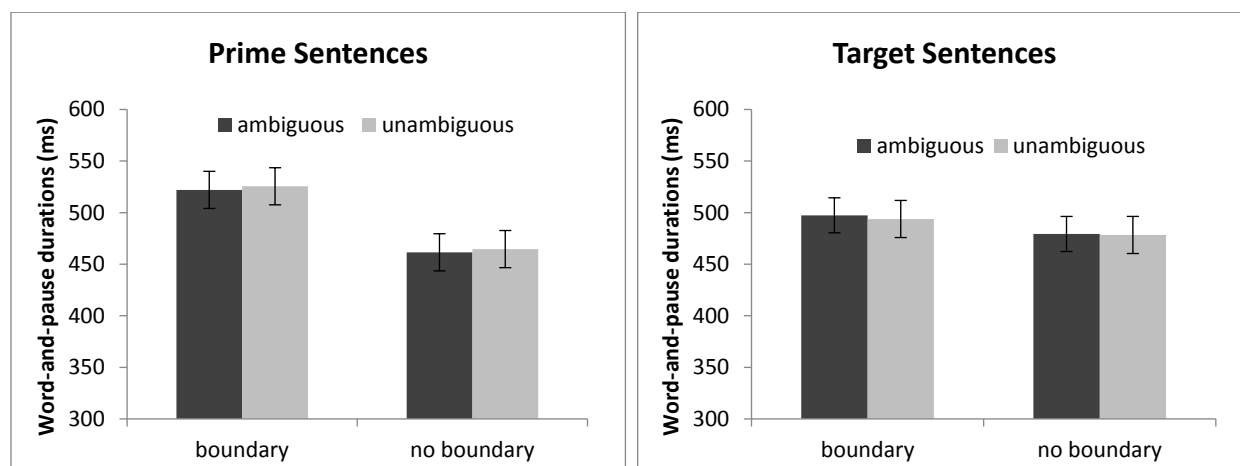**Prime Sentences**

**Target Sentences**

Figure 5: Word-and-Pause Durations
Mean word-and-pause durations for the critical regions of the a) prime  and b) target  sentences, broken down by Boundary and Ambiguity conditions. Error bars represent 95% confidence intervals.

The overall analysis of perceived boundaries (Table 3a) revealed significant main effects of

Sentence Position, Ambiguity, Boundary, and interactions between Sentence Position and

Ambiguity as well as Sentence Position and Boundary. The perceptual coder for this study was

more likely to perceive a boundary at the critical location in prime sentences than in target

sentences. Furthermore, she was more likely to perceive a boundary in an *unambiguous* sentence

than an ambiguous sentence in the primes but not the targets. She was also more likely to

perceive a boundary in a sentence where the prime contained a boundary, and again this effect differed across primes and targets. Following up on these interactions, an analysis restricted only to target sentences revealed no effects of Ambiguity and Prime Boundary. Thus, this coder's perception of a boundary at the critical location in the targets was not affected by prime ambiguity or by prime boundaries.

A similar pattern was observed again with word-and-pause durations (Figure 5). The analysis of word-and-pause durations revealed significant main effects of Sentence Position and Boundary, and an interaction between Position and Boundary (Table 3b). Participants produced the words in the critical region of the targets faster than the primes, although the effect was numerically small. Participants also spent less time producing the words in this region when the prime sentence did not contain a boundary, and the size of this effect was larger in primes (Figure 5a) than targets (Figure 5b). A follow-up analysis restricted to target sentences revealed a main effect of Boundary, but no interaction between Boundary and Ambiguity: participants produced the words in the critical region of target sentences more slowly when the prime contained a boundary, but this effect was not larger when the prime sentence was ambiguous.

Table 3. Results of analyses of perceived boundary production and word-and-pause durations at the critical sentence region of all sentences (primes and targets). Model (a) includes random by-item and by-participant intercepts. Model (b) includes random by-participant and by-item intercepts, and additive random slopes for estimates of the effect of Boundary.

| Predictor | a) Boundary production | | | b) Word-and-pause durations | | |
|---|---|---|---|---|---|---|
| | Estimate | St.error | z-value | Estimate | St.error | t-value |
| *Critical sentence region* | | | | | | |
| Intercept | 0.812 | 0.125 | 6.51* | 494 | 146 | 33.78* |
| Sentence Position | -1.05 | 0.0959 | -10.9* | -7.94 | 3.91 | -2.03* |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ambiguity | 0.738 | 0.0962 | 7.674* | 0.047 | 3.91 | 0.01 |
| Boundary | -0.354 | 0.0961 | -3.69* | -38.57 | 6.11 | -6.32* |
| Position * Ambiguity | -1.32 | 0.191 | -6.93* | -0.569 | 7.81 | -0.07 |
| Position * Boundary | 0.455 | 0.190 | 2.39* | 45.37 | 7.82 | 5.80* |
| Ambiguity * Boundary | 0.00406 | 0.192 | 0.021 | 3.60 | 7.81 | 0.46 |
| Ambiguity * Boundary * Position | -0.247 | 0.381 | -0.649 | 1.50 | 15.6 | 0.10 |

In sum, when participants were exposed to a boundary that provided a means of disambiguating the syntax of the prime sentence, they still did not persist in using the boundary in the following target sentence. This replicates Experiment 1 and shows that IPB priming did not occur even under conditions where boundaries were highly salient and meaningful to the listener.

Our results did show an effect of ambiguity in the perceptual measure of boundaries that was not predicted: boundaries were produced more often in the repeated *unambiguous* prime sentences. It is possible that our coder was more likely to perceive a boundary that supports a particular syntactic interpretation when that syntax is not ambiguous, as there may be some effects of internal prosody on this measure. Further, the perceptual coder coded all the target sentences before coding the primes (to avoid practice effects and to help keep the coder blind to condition), which may explain why this subjectivity impacted primes more than targets. As this was the only inconsistency with the objective duration measure, and as it does not change the interpretation of the boundary priming effect, we do not discuss it further.

Based on the results from Experiments 1 and 2, it appears that speaking rate (which persists) and intonational boundaries (which do not) may have differing types of underlying representations or may be planned at different processing stages. However, it is an open question as to what it is about the processes underlying boundary production that resists priming. Tooley

et al. (2014) argued that the *lack* of a separable representation is responsible for this effect. Rather than engaging an independent representation for intonational boundaries in speech production, there are direct connections between semantic/syntactic planning systems and articulators that trigger boundary production at points at which they are needed.  Because there is no overt prosodic representation across the sentence during production, there is nothing to prime.

It is also possible that there *is* an abstract representation for boundaries and that the relationship between intonational boundaries and other levels of linguistic representation inhibits priming.  For example, it could be the case that the planning requirements for the syntactic and semantic systems that drive boundary placement overwhelm any impact of the boundary representation from the prime.  If that is the case, one might expect other aspects of prosody that are also linked to higher levels of linguistic representation to be similarly immune to effects of priming.  We test this prediction in Experiment 3 by investigating priming of pitch accents.

## Experiment 3

Pitch accents are signalled by a movement in the F0 contour, increased intensity, and lengthening, and like intonational boundaries, they are tightly linked to semantic and syntactic structure. They are also related to focus and discourse structure (Wagner & Watson, 2010): pitch accents can appear throughout an utterance to satisfy metrical requirements but they are typically used in English to signal information that is new (or focused), unpredictable or important (Bolinger, 1972). However, because they are constrained by syntactic information, pitch accent placement is optional at times (Selkirk, 1984). Here, we exploit this optionality to determine whether pitch accents are similar to IPBs in their resistance to priming.

There are several technical definitions of focus in the literature, but here, we will use it to refer to words or syntactic phrases that are new or important in a sentence. If a syntactic phrase is

focused, there is some optionality in where a pitch accent can occur (Selkirk, 1995;

Gussenhoven, 1983). For example, in sentences 3a and 3b, the head of the noun phrase *book*

*about the Greeks* is *book*. The prepositional phrase that modifies *book* is an argument, i.e., a

word or phrase that satisfies a core semantic requirement of a head (see Gibson & Schutze, 1999,

for a more precise definition of argumenthood). For example, all books have a topic, so the

prepositional phrase "about the Greeks" specifies a semantic property of the head *book*. In

sentences 3c and 3d, the prepositional phrase is a modifier, i.e., a word or phrase that modifies

the head but does not satisfy a core semantic property of a head (being next to some thing or

some person is not an intrinsic property of the definition of a book).

3a) *The professor assigned the book about the GREEKS to the class.*

3b) *The professor assigned the BOOK about the GREEKS to the class.*

3c) *\*The professor assigned the book next to the GREEKS to the class.*

3d) *The professor assigned the BOOK next to the GREEKS to the class.*

Arguments play a key role in the distribution of pitch accents in focused phrases. It is

grammatical for a pitch accent to occur either on the argument of a head (3a) or on both the head

and its argument (3b). In contrast, for modifiers, the pitch accent must occur on both the head

and its modifier (3d). If it occurs only on the modifier (3c), the sentence sounds less acceptable.

Thus, for focused phrases with arguments, there is optionality in where a pitch accent can occur

(Selkirk, 1984).

This experiment investigated priming of optional pitch accents. As in previous

experiments, participants listened to and immediately repeated back the prime sentences they

heard. The sentences either had pitch accents only on the second of the two nouns (3a), or on

both the head noun and the noun within the modifier (3b). On the following target trial, the

participants silently read a novel sentence (with the same syntactic structure as the prime) and repeated it aloud.

It is highly likely that an abstract representation supporting pitch accent production does exist (e.g., Selkirk, 1995; Gussenhoven, 1983; Pierrehumbert & Hirschberg, 1990; and many others). The complex constraints that govern syntax, focus, and pitch accents would require an abstract representation for pitch accent structure, if only to track where accents have and have not occurred so that the speaker can ultimately produce a grammatical sentence. In addition, linguists have proposed a catalogue of pitch accent types that convey different semantic and pragmatic interpretations, such as introducing a new referent or signalling a contrast between a referent and something previously mentioned in the discourse (e.g., Pierrehumbert & Hirschberg, 1990). These would require an independent level of representation mapping the acoustic form to meaning.

Thus, priming of pitch accents provides an ideal test case for the two hypotheses discussed in the previous section. One hypothesis is that prosodic elements that are determined by other linguistic levels do not prime. If a lack of priming is due to some aspects of prosody being controlled by higher-order linguistic levels of representation (such as discourse, syntax, and semantics), then we would expect to see no priming for either IPBs or pitch accents. The second hypothesis is that elements of prosody that are not represented abstractly do not prime. In previous work (Tooley et al., 2014), we proposed that intonational boudnaries do not prime because they are represented abstractly by speakers. Because we know that pitch accents must be represented abstractly, they serve as an ideal comparison case. If priming is only absent when a linguistic phenomenon is not represented abstractly, we would expect priming of pitch accents in this experiment.

**Method**

*Participants*

44 students from Texas State University participated for course credit.

*Materials*

The experimental items consisted of 40 main clause sentences in which the object of the verb was a noun followed by a prepositional phrase (e.g., *The Mexican billionaire purchased the photo of the landscape at the auction*; Appendix C). Each sentence was randomly yoked to another sentence to create 20 prime-target pairs. The pitch accenting manipulation was created by having a trained speaker record two versions of each of the sentences: a control condition where only the noun in the prepositional phrase was accented (e.g., *The Mexican billionaire purchased the photo of the LANDSCAPE at the auction*), and a priming condition where both the head noun and the noun in the prepositional phrase were accented (e.g., *The Mexican billionaire purchased the PHOTO of the LANDSCAPE at the auction*). The critical word in these sentences is therefore the head noun (e.g., *photo*). Unlike Experiment 1, the stimuli were not created via splicing, as attempts at cross-splicing yielded less than natural sounding sentences. The accented version of the critical word across sentences had a longer mean duration (0.413 vs. 0.341 sec), greater intensity (63.74 vs. 59.45), lower minimum pitch (173.13 vs. 196.32), and higher maximum pitch (249.53 vs. 225.89) than the unaccented version (all $ps < 0.01$).

The two experimental conditions, and the use of each sentence as a prime or as a target, were counterbalanced across four lists. Thus, each participant saw each sentence in only one condition, either as a prime or as a target. Within lists, each participant received 10 items in each of the two experimental conditions. Three filler sentences intervened between all prime-target

pairs. Filler sentences were the same as those used in Experiment 1, but were recorded by the

same speaker who produced the experimental items and included at least one accented word.

*Procedure*

The procedure for Experiment 2 was the same as in Experiment 1.

*Scoring and Analysis*

Responses were excluded from analysis if participants changed the syntax of the sentence, did

not produce two nouns in the critical prepositional phrase, paused for extended periods of time,

or produced disfluencies at or near the critical region. Minor wording changes were acceptable.

This left 1282 trials (out of 1760 total trials) for analysis.  Participants' pitch accenting was

assessed in two ways: one based on subjective perception and one based on objectively measured

speech correlates of pitch accenting. The perceptual coder rated the perceived level of pitch

accenting on the critical word relative to the other words in the sentence on a 4-point scale.

Another coder annotated (marked) the onsets and offsets of the critical words using PRAAT. We

then extracted measures of average pitch, intensity, and duration on the critical words.

Analyses were also implemented in R (R Development Core Team, 2008), using linear

mixed effects models for the subjective and objective measures of pitch accenting. All models

included Prime Accenting (accented vs. unaccented) and Sentence Position (prime vs. target) as

contrast-coded fixed effects, and participants and items as random effects.

**Results and Discussion**

*Perceptual Measure of Pitch Accenting*

The critical words in the reproductions of the prime sentences were rated as being more accented

when the prime recording also contained accenting on this word (Figure 6). This effect was not
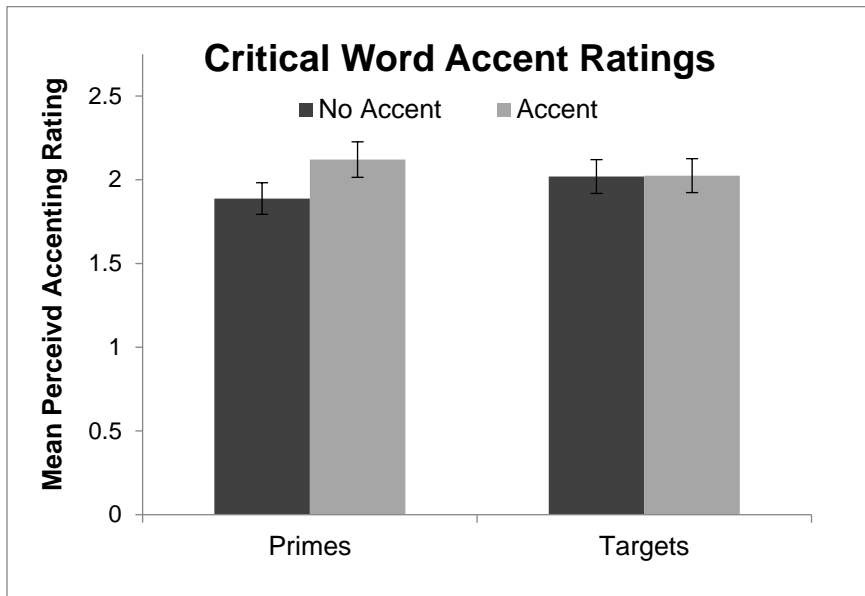
present in the target sentences.



Figure 6: Perceived Ratings of Pitch Accenting
Mean perceived ratings of pitch accenting on the critical word in both the prime (left) and target (right) sentences broken down by the accenting condition (no accent vs. accent). Error bars represent 95% confidence intervals.

The overall analysis of ratings of perceived levels of pitch accenting yielded a main effect of Prime Accenting and an interaction between Prime Accenting and Sentence Position (Table 4). Follow-up analysis of the target sentences revealed no significant effect of Prime Accenting. Thus, participants tended to accent the critical word in their repetitions of the prime sentences more when they heard a prime with the critical word accented, but this effect did not persist into the target sentences.

Table 4. Results of analysis of perceived pitch accenting on the critical word in the prime and target sentences. The model includes random slopes and intercepts for participants and items.

| | Perceived Level of Pitch Accenting | | |
|---|---|---|---|
| Predictor | Estimate | St.error | t-value |

| | | | |
|---|---|---|---|
| Intercept | 1.997 | 0.062 | 32.31* |
| Pitch Accenting | 0.136 | 0.048 | 2.85* |
| Sentence Position | 0.008 | 0.059 | 0.130 |
| Pitch Accenting * Sentence Position | -0.222 | 0.095 | -2.32* |

*Measures of Pitch, Intensity, and Duration*

Figure 5 shows the mean pitch, intensity, and durations of the critical words in the primes and targets. The pitch analysis showed no effects of Prime Accenting on pitch in either the primes or the targets (Table 5a). The analyses of intensity and duration showed main effects of Sentence Position (primes were louder than targets, and primes were shorter than targets), but no effects of Prime Accenting and no interactions (Table 5b, 5c). Thus, while the primes differed in intensity and duration from the targets, Pitch Accenting had little effect on acoustic measures for the critical words in target sentences.
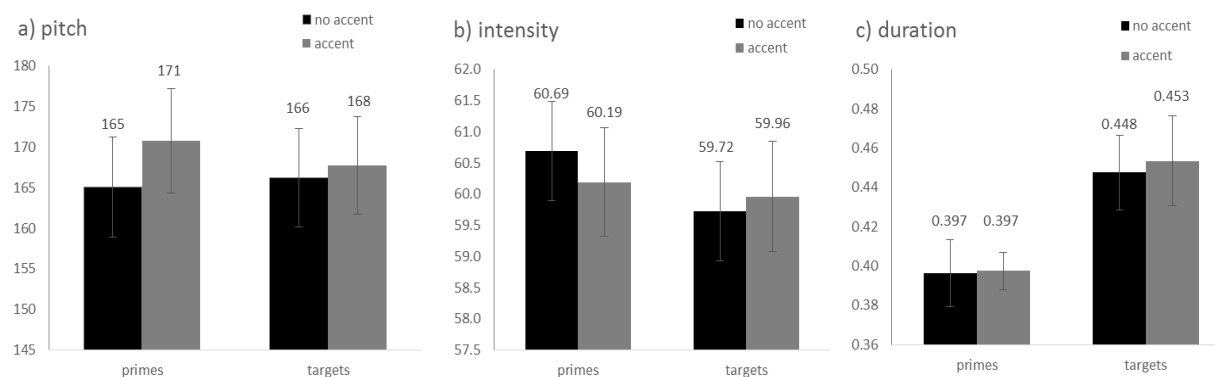


Figure 7: Mean measurements of a) pitch (Hz) accenting, b) intensity (dB), and c) duration (sec.) of the critical word in both the prime (left) and target (right) sentences broken down by the accenting condition (no accent vs. accent). Error bars are standard errors.

Table 5. Results of the analysis of a) pitch, b) intensity, and c) duration of the critical word in the prime and target sentences. The model includes random slopes and intercepts for participants and items.

| Predictor | Pitch | | | Intensity | | | Duration | | |
|---|---|---|---|---|---|---|---|---|---|
| | Est. | St.error | t | Est. | St.error | t | Est. | St.error | t |
| Intercept | 169 | 5.91 | 28.39* | 60.20 | 0.87 | 68.85* | -0.44 | 0.02 | 21.8* |
| Sentence Position | -1.95 | 1.47 | -1.32 | -0.49 | 0.24 | -2.07* | -0.06 | 0.02 | 3.28* |
| Pitch accenting | 1.35 | 1.50 | 0.90 | .34 | 0.22 | 1.54 | -0.02 | 0.02 | .87 |
| Pitch x Sentence Pos. | -2.26 | 3.46 | -0.65 | .37 | 0.44 | .83 | -0.02 | 0.05 | .33 |

In sum, results from the analysis of pitch accenting suggest that pitch accenting is not readily amenable to priming. These results are remarkably similar to those for IPB priming in Experiments 1 and 2. Participants do appear to store the prosodic information that they hear in the prime sentence, as it clearly influences the prosody they use when repeating that sentence (even with minor wording changes). However, there is no evidence that their experience with the prime, and its stored prosodic information, affects the pitch accenting of target sentences. Notably, this is again quite distinct from priming effects observed for syntactic structure, word meaning, and even speaking rate, where experience with the prime has an immediate, observable influence on the target. Theoretically, this result would suggest that both pitch-accenting and intonational phrase boundaries are planned in conjunction with other representations, such as

syntax and message level representations, during sentence production.

## General Discussion

Three experiments showed that some aspects of prosody (i.e., intonational phrase boundaries and pitch accenting) are not amenable to priming while another aspect of prosody (speaking rate) is. This lack of priming for IPBs and pitch accenting was observed despite retention of prosodic representations in repetitions of the primes, even when those repetitions involved minor content word changes. This was the case even when IPBs served a disambiguating function (Experiment 2). Thus, we propose that this difference in priming across experiments may reveal an important distinction in how more *linguistic* aspects of prosody (i.e., aspects of prosody that convey linguistic information to the listener, such as cues to syntax, semantics, and discourse focus) are represented relative to more *paralinguistic* aspects of prosody (such as speech rate). These findings are consistent with a model of production where speaking rate is planned *separately* but pitch accenting and intonational phrase boundaries are planned *together* with other types of linguistic representations. We outline such a model below.

*Incorporating Prosody into a Model of Speech Production*

The model postulated by Tooley et al. (2014) suggested that boundary production is the result of interactions between different levels of representation (i.e., syntax, semantics, and discourse) as well as processing resource constraints of the speaker. As such, a separate, abstract level of representation for the prosodic phrasing of an entire sentence is not included in the model. Instead, boundaries are initiated as needed by other levels of representation – specifically, by "go" signals from those planning stages to the articulation stage. However, given that pitch accenting is also not amenable to priming (and that this aspect of prosody is widely assumed to be abstractly represented), it is possible that IPBs are also represented abstractly, but priming for

these representations is not strong enough to survive the processes related to planning the

linguistic structure of the subsequent target sentence. Furthermore, as speech rate can be primed,

it is likely planned at a more global level, rather than in direct concert with other linguistic

representations (e.g., syntax).

A model of speech production that incorporates prosodic planning would therefore need

to include a global processing stage or controller that sends information to the articulators to

modulate speaking rate. This model specification is consistent with a growing body of research

that has found persistence for speaking rate from one sentence to the next across various ages

and tasks (Finlayson, Lickley, & Corley, 2010; Hupp & Jungers, 2009; Jungers et al., 2002;

Jungers & Hupp, 2009). Such a model would also likely include an abstract processing stage for

linguistic aspects of prosody. However, this processing stage would have direct communication

with message-level and syntactic/semantic level representations (Figure 8), and would then send

prosodic plans to the articulation processing stage. Signals from the message-level stage would

convey information about the givenness and newness of referents to the prosodic planning stage,

so that words could be accented or deaccented accordingly. Furthermore, information from the

syntactic stage would need to be conveyed to plan intonational phrase boundaries that coincide

with phrasal boundaries and pitch accenting on particular words to maintain the hierarchy of

pitch accenting produced across different clauses, phrases, and the entire sentence. Additionally,

processing difficulty experienced during formulation could be communicated to the prosodic

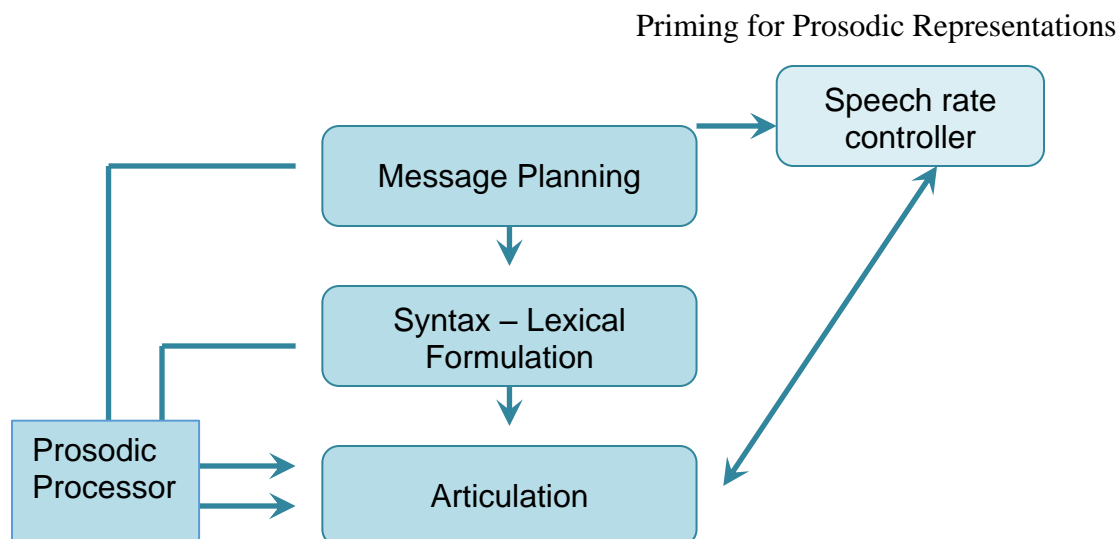processor to initiate a boundary to allow processing to "catch up."

Figure 8. Model of Speech Production Including Prosodic Planning
Message and structural formulation systems send signals to a prosodic signalling system that initiates prosodic production in the articulators. However, speech rate is controlled at a separate processing stage (the speech rate controller).

Such a model can account for the results of the current studies. However, given the scarcity of research in this area, only a few dimensions of prosody have been investigated for potential priming effects. Additional priming research for other aspects of prosody, in different contexts, is needed to determine whether such a model can account for a broader range of findings. Interestingly, the aspects of prosody that have been found to be least amenable to priming are those that are also inherently more linguistic in nature. In contrast, speaking rate, which is paralinguistic aspect of prosody, does show robust priming. We propose that this distinction deserves further scrutiny.

*Social Influences on Priming*

A *paralinguistic* aspect of prosody, like speaking rate, often conveys non-linguistic information to the listener (Crystal, 1976; Fujisaki, 1997), such as the internal emotional state of the speaker (Frick, 1985; Williams & Stevens, 1981), or the speaker's competence or benevolence (Brown, 1980). This implies that priming for aspects of prosody may depend on the extent to which those

aspects interact with social variables.

Social factors have been shown to mediate priming at the phonetic and syntactic levels. For example, priming can influence pronunciation in conversational tasks (Pardo, 2006), and the degree to which a participant shows phonetic convergence with their conversational partner depends jointly on their gender and role in the conversational task (Bilious & Krauss, 1988; Pardo, Jay, & Krauss, 2010). Similarly, stronger structural priming is observed when participants have a positive social impression of their conversational partners and weaker when they have a negative social impression of their partners (Balcetis & Dale, 2005; but see Branigan et al., 2010, and Heyselaar, Hagoort, & Segaert, 2017). Furthermore, recent studies of structural priming and alignment showed alignment of structure only when participants were interacting with other participants or a human-like avatar (Heyselaar et al., 2017), and not when they were interacting with a computer (Fehér, Wonnacott, & Smith, 2016, using in an artificial language).

These findings raise the possibility that priming of more linguistic aspects of prosody might occur in the presence of an interlocutor or in a conversational context, neither of which were present in the current studies. However, repetition of syntactic structure can be elicited reliably in both communicative and non-communicative settings, as the role of a syntactic structure in conveying relational information in an utterance does not depend on the presence or absence of an interlocutor. Even if the communicative value of prosody is contingent on the production context in a way that the communicative value of syntax is not, priming effects of speaking rate have now been observed in multiple single-person studies (the current study as well as Jungers & Hupp, 2009). Thus, if conversation is a prerequisite for IPB priming, this would make IPB representations entirely unlike other aspects of language that have been found to prime.

*Conclusion*

The current study investigated priming for three aspects of prosody. Speaking rate was found to persist from one sentence to a subsequent sentence, but boundary placement and pitch accenting were not. These findings replicate and extend previous work on priming of aspects of language that are part of the spoken language signal (i.e., prosody) but separate from the meanings of individual words (Jungers & Hupp, 2009; Tooley et al., 2014). Finding priming for a paralinguistic aspect of prosody (i.e., speaking rate) but not more linguistic aspects of prosody (intonational phrase boundaries and pitch accenting) may suggest a difference in how these different aspects of prosody are represented and planned during language production.

Acknowledgments

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Appendix A

Sentences with relative clauses and main clauses presented in Experiment 1. The locations of the boundaries are indicated with forward slashes.

*Sentences with relative clauses:*
The apprentice who melted the gold // had not slept in days.
The lender who approved the loan // negotiated a good interest rate.
The clown who entertained the children // wore a silly hat.
The witch who lived in the old house // had three black cats.
The billygoat that roamed the cliffs // was incredibly nimble.
The men who survived the battle // huddled around the fire.
The dolphin that tossed the ball // wanted a reward for his trick.
The jeweler who set the stone // charged a large fee.
The guard who worked the night shift // had a hard time staying awake.
The dancer who owned the studio // was in excellent physical condition.
The professor who gave the lecture // had a pronounced lisp.
The nurse who minded the patients // had a kind smile.
The monkey that stole the hat // refused to give it back.
The woman who watered the flowers // enjoyed bright colors.
The queen who summoned the painter // wanted a new mural.
The traveler who visited the temple // loved exotic places.
The dog that pawed the door // needed to be let out.
The violinist who performed the solo // got a standing ovation.
The firefighter who stopped the blaze // was given a medal.
The realtor who sold the property // got a large commission.

*Sentences with main clauses:*
The mobster shot the men // for their disloyalty.
The duck splashed the water // as it landed on the lake.
The botanist studied the plant cells // with a powerful microscope.
The girl bought new clothes // at the mall today.
The pianist rehearsed the piece // for hours and hours.
The biologists freed the whale // once it had fully healed.
The caterer set the trays // on the long banquet table.
The gardener gave the squash // to the family next door.
The movie star accepted the role of Hamlet // from the director.
The engineer designed the bridge // that crossed the bay.
The accountant reviewed the material // before the certification exam.
The pigeon followed the baby // around the park.
The valet requested the shift // with the most business.
The brewer studied the recipe // for the new pale ale.
The jogger patted the dog // when he stopped for a drink.
The motorist bumped the new car // while parking.
The minister asked the congregation // to put money in the offering plate.
The cook divided the soup // into four equal portions.
The scientist screened the samples // for the deadly disease.
The miners struck gold // after digging for a month.

Appendix B

Unambiguous and ambiguous sentences presented in Experiment 2. The locations of the boundaries are indicated with forward slashes.

| Unambiguous Sentences | Ambiguous Sentences |
| --- | --- |
| She put the money for the basket // on the table. | She put the money in the basket // on the table. |
| He threw the marble from the bucket // in the yard. | He threw the marble in the bucket // in the yard. |
| He laid the ribbon for the gift // in the box. | He laid the ribbon by the gift // in the box. |
| He dropped the piece for the puzzle // on the floor. | He dropped the piece by the puzzle // on the floor. |
| She set the key to the jewelry box // on the shelf. | She set the key in the jewelry box // on the shelf. |
| He spilled the ink for the pen // on the desk. | He spilled the ink by the pen // on the desk. |
| He placed the stamp from the envelope // in the pile. | He placed the stamp on the envelope // in the pile. |
| I left the bill for the pint // on the bar. | I left the bill by the pint // on the bar. |
| He tossed the shirt from the pile // in the trash. | He tossed the shirt on the pile // in the trash. |
| She dumped the garnish for the dish // on the tray. | She dumped the garnish on the dish // on the tray. |
| I dumped the receipts for the wine // on the shelf. | I dumped the receipts by the wine // on the shelf. |
| She tossed the penny from the water // on the mat. | She tossed the penny in the water // on the mat. |
| He left the jacket for the suit // on the bed. | He left the jacket on the suit // on the bed. |
| She placed the seed for the soil // in the hole. | She placed the seed on the soil // in the hole. |
| She spilled the water for the tea // on the burner. | She spilled the water by the tea // on the burner. |
| He set the lid for the pot // on the porch. | He set the lid by the pot // on the porch. |
| I dropped the cherry for the sundae // in the bowl. | I dropped the cherry on the sundae // in the bowl. |
| She laid the note for the folder // on the table. | She laid the note by the folder // on the table. |
| She threw the tag for the hat// in the bin. | She threw the tag by the hat // in the bin. |
| He put the keys for the box // in the sack. | He put the keys on the box // in the sack. |
| She put the sandwich // into the bag on the chair. | She put the sandwich // in the bag on the chair. |
| She laid the dolls // into the basinet on the ground. | She laid the dolls // in the basinet on the ground. |
| I tossed the silverware // onto the table in the hall. | I tossed the silverware // on the table in the hall. |
| He dumped the sand // into the pail on the beach. | He dumped the sand // in the pail on the beach. |
| He laid the towels // in a pile in the closet. | He laid the towels // on the pile in the closet. |
| He put the wrench // into the toolbox on the counter. | He put the wrench // in the toolbox on the counter. |
| I dumped the laundry // into the basket on the couch. | I dumped the laundry // in the basket on the couch. |
| She tossed the phone // into the bag on the bed. | She tossed the phone // in the bag on the bed. |
| She threw the knife // into the boat in the river. | She threw the knife // in the boat in the river. |
| She dropped the cans // into the bag in the pantry. | She dropped the cans // in the bag in the pantry. |
| I spilled the coffee // onto the saucer on the tray. | I spilled the coffee // on the saucer on the tray. |
| I left the bottle // in a bag on the bench. | I left the bottle // in the bag on the bench. |
| He dropped the bulb // into the bucket on the hill. | He dropped the bulb // in the bucket on the hill. |
| He threw the crayon // into the box in the drawer. | He threw the crayon // in the box in the drawer. |
| He left the menu // on a desk in the study. | He left the menu // on the desk in the study. |
| She spilled the oil // onto the mat on the sidewalk. | She spilled the oil // on the mat on the sidewalk. |
| She placed the flag // onto the pole in the grass. | She placed the flag // on the pole in the grass. |
| She set the mitten // in a box on the stairs. | She set the mitten // in the box on the stairs. |
| He set the toys // on a blanket on the sofa. | He set the toys // on the blanket on the sofa. |
| I placed the note // into the file in the cabinet. | I placed the note // in the file in the cabinet. |

Appendix C

Experimental sentences used in Experiment 3. Uppercase indicates accented words and italics indicates the critical (manipulated) word.

The Mexican billionaire purchased the *PHOTO* of the LANDSCAPE at the auction.
The club treasurer collected the *DUES* for the MEMBERSHIP after the meeting.
The Kansas politician protested the *DESTRUCTION* of the CITY by the rebels.
The high school senior mailed the *APPLICATION* for the SCHOLARSHIP to the company.
The Jamaican sprinters saluted the *STATUE* of the WARRIOR at the track.
The preschool class learned the *RIDDLE* about the NUMBERS after their naps.
The nursing instructor explained the *DIAGRAM* of the HEART to the audience.
The radio deejay played the *SONG* about the BREAKUP after the commercials.
The dealership president docked the *PAY* of the MECHANICS from the union.
The team doctor packed the *BOXES* of the MEDICINE for the away game.
The varsity quarterback declined the *OFFER* of the SPONSORSHIP from the president.
The Ethiopian runner beat the *WINNER* of the OLYMPICS at the Chicago marathon.
The chorus dancer read the *ROLE* of the LEAD at the audition.
The circus freak performed the *SHOW* about the TIGER behind the screen.
The label representative dropped the *TRAY* of the DRINKS at the party.
The hospital intern conducted the *SEARCH* of the FLOOR at the shift change.
The company janitor emptied the *BIN* for the RECYCLING at the end of the shift.
The store manager released the *NAMES* of the WINNERS over the radio.
The precinct officer saw the *GRAFFITI* of the GANG on the brick wall.
The city arborist checked the *HEALTH* of the TREES at the building site.
The French chef added the *ZEST* of a LEMON to the dish.
The literature professor assigned the *BOOK* about the GREEKS to the class.
The job candidate joined the *LINE* for the COFFEE after his interview.
The building engineer inspected the *CLAIMS* about the LEAKS on the third floor.
The division secretary started the *RUMORS* about the LAYOFFS at the meeting.
The university scientist stole the *BLUEPRINTS* of the DEVICE at the conference.
The state senator raised the *ISSUE* of the DROUGHT at the hearing.
The estate butler saw the *GHOST* of the GARDENER on Halloween night.
The festival partygoers liked the *PORTRAIT* of the QUEEN by the fountain.
The tournament champion studied the *LIST* of the WORDS in the hotel lobby.
The royal jester told the *STORY* about the SIEGE to the court.
The school principal called the *ASSEMBLY* of the STUDENTS in the school play.
The dairy worker brought the *BOTTLES* for the MILK to the barn.
The supreme court heard the *CASE* of the MURDER at the agency.
The forest ranger monitored the *CONSTRUCTION* of the TRENCH from his office.
The college dean fired the *HEAD* of the DEPARTMENT after the faculty meeting.
The start-up founder hired the *STAFF* of the BAR from the local university.
The station agent punched the *TICKETS* of the PASSENGERS on the train.
The event coordinator left the *LIST* of the ATTENDEES at the coffee shop.
The FBI inspector questioned the *WITNESS* of the ROBBERY at the police station.