Implementation of selective attention in sequential word production

Nazbanou Nozari (nozari@jhu.edu)
Department of Neurology, Department of Cognitive Science, Johns Hopkins University,
1629 Thames Street, Suite 350, Baltimore, MD 21231, USA

Gary S. Dell (gdell@cyrus.psych.illinois.edu)
Department of Psychology, University of Illinois at Urbana-Champaign,
833 Psychology Bldg., 603 E. Daniel St., Champaign, IL 61820, USA

Kyle Schneck (kschneck@udel.edu)
Department of Linguistics and Cognitive Science, University of Delaware,
125 E. Main St., Newark, DE 19711

Barry Gordon (bgordon@jhmi.edu)
Department of Neurology, Department of Cognitive Science, Johns Hopkins University,
1629 Thames Street, Suite 350, Baltimore, MD 21231, USA

Abstract

We studied changes to the pattern of speech errors as a function of selectively attending to one word in a sequence to learn how attention is implemented in language production. Three hypotheses were tested: (1) attention specifically inhibits the past, (2) attention enhances the activation of the present without affecting the past or the future, and (3) attention decreases priming of the future. In Experiment 1, using a model of sequential word production, we simulated the pattern of anticipatory and perseveratory errors on the attended words, and compared them to empirical error data. Our findings support a model in which attention only affects the present. Experiment 2 tested the prediction of this model regarding the error patterns on the word following the attended word. These results were also compatible with a transient enhancement in the activation of present that does not affect the production of the future words.

Keywords: Language production; Selective attention; Structural frame; Perseveration, Anticipation; Speech error, Cognitive control; Executive function

Introduction

We can selectively attend to certain objects in the visual scene while ignoring others. As a consequence we process the attended objects more accurately, at a cost to objects we choose not to attend to. The mechanisms behind this selective attention are well studied in perception, and range from competition for representations in the receptive field of individual neurons to synchronization of neural populations mediated by a fronto-parietal control network that lies largely outside of sensory regions (Gazzaley & Nobre, 2012). On the other hand, selective attention in self-produced sequences, such as multi-word utterances, is less well understood, and is the topic of the current study.

There are at least two fundamental differences between selective attention during language production and during visual perception. For one, words that are not placed in the focus of selective attention must still be fully processed for production. For example, even though the speaker may be attending to "three" in "I have been here for *three* hours" in response to an interlocutor who tells him "You have only been waiting for an hour", he must still plan and produce all the other words that are not in special focus of attention. Furthermore, the sequence unfolds over time, so competition must be implemented in a system with temporal sequencing. These differences motivate the direct study of the effects of selective attention on production of multi-word utterances, instead of relying strongly on extrapolations from visual attention.

Effects of attention on language production remain, for the most part, unstudied. Most research that looks at attention in the context of speaking is, in essence, studying attention in visual perception, rather than attention in production. For example, many studies have shown that the focus of attention on the visual scene predicts the utterance structure (e.g., Griffin & Bock, 2000), and that manipulating bottom-up attention within the scene affects the choice of linguistic structure (e.g., Bock, Irwin, & Davidson, 2004; Gleitman, January, Nappa, & Trueswell, 2007; Tomlin, 1997; but see Kuchinsky, Bock, & Irwin, 2011). Similarly, research on the effects of attention on suppressing competing pictures/words during picture naming speaks to inhibition of a perceptual competitor that is *not* to be produced (e.g., Oppermann, Jescheniak, & Görges, 2013; Piai, Roelofs, & Schriefers, 2012). While informative about how information is selected for production, none of these studies address the consequences of paying special attention to, say, one word in a sequence of words all of which are to be produced.

Nozari and Dell (2012) presented the first empirical study of the effect of selective attention on the production of multi-word utterances. Participants produced 4-word tongue-twisters in which either one or none of the words was singled out. Three different manipulations of attention all resulted in the same pattern: selective attention during production resulted in the more accurate production of the attended and less accurate production of the unattended (see also Nozari & Thompson-Schill, 2013 for linking this effect to the left prefrontal cortex). To investigate the underlying mechanism of this effect, Nozari and Dell (2012) reported an analysis of the origin of errors. They divided errors on the unattended words into two groups. The first group were errors which originated from the attended word (AttOrg+; e.g., producing "ring" for "wing", where the origin of the erroneous segment /r/ was the attended word "**wrist**"). The rest were errors that did not originate from the attended word (AttOrg−; e.g., producing "winf" for "wing", where the origin of the erroneous segment /f/ was not the attended word "**wrist**"). The authors found no evidence of increase in the proportion of AttOrg+ errors as a function of attention. They argued that this finding ruled out the simplest implementation of attention, in which the attended word is given a large jolt of activation, because the extra activation should have caused more segmental migrations from the attended word and increased the proportion of AttOrg+ errors.

While Nozari and Dell's finding refuted one model, it remained unclear what the correct way of implementing attention in language production is. The present study investigates this issue in sequential word production. Except for the first and the last words in multi-word utterances, every other word is spoken amid both past and future words. Fluent and error-free production depends on successful inhibition of the past, correct selection of the present, and timely priming of the future. Failure of any of these operations results in erroneous or disfluent speech. Poor inhibition of the past or failure to activate the present can result in perseveration errors, errors in which the already-spoken words, or parts of them, are repeated in place of the current target. Disproportionally strong priming of the future leads to anticipation errors, where the words, or parts of them, that must be uttered in the future slip into the production of the current utterance. Finally, late or impotent priming of the future results in disfluent speech. Selective attention may modulate any of these processes.

The current study uses a computational model to test whether selective attention affects the suppression of the past, the activation of the present, or the priming of the future. The model is a modified version of a model of serial order in language production proposed by Dell, Burger, and Svec (1997; Figure 1). The goal of the simulations is not to test the model, but rather to use it to understand attention, in much the same way that, for example, a signal detection model is used to understand the effect of some manipulation on recognition memory or perception. The model offers parameters, variation in each of which may or may not be able to explain the effects of attention on the data.

Dell et al.'s (1997) model has two main components, a plan for the words to be produced and a structural frame for ordering these words. The plan has connections to all lexical items relevant to the current sequence with equal weight *w*. This means that these words can be activated and selected through the plan, but there is no information about which word has to be produced first, second, etc. Ordering is achieved through binding with the structural frame.

Unlike the plan, the structural frame is not specific to words in the current sequence. Instead, it supports activation of words in certain positions. Figure 1 shows an example, in which it is time to produce a word in position 2. While all weights between the plan and the words remain *w*, the structural frame differentially supports the activation of words in positions 1, 2, and 3. Word 1 (past) receives no support from the frame (i.e., weight = 0) because it has already been produced. Word 2 (present) receives support with weight *k*. Word 3 (future) also receives some support with weight *b*, because it needs to be primed for production next. Specifically, the input of activation to the words in the sequence is a function of the (uniform) support they receive from the plan multiplied by the (differential) support they receive from the structural frame. Two more parameters affect this activation: passive decay (*d*), and active suppression after production, which we index by residual activation given to each word once it has been produced (*c*). The activation of past, present, and future after retrieval has gone on for *n* time steps is (Equations 1-3):

$$Activation(past) = c(1-d)^{n} \qquad (1)$$
$$Activation(present) = nwk(1-d)^{(n-1)} \qquad (2)$$
$$Activation(future) = nwb(1-d)^{(n-1)} \qquad (3)$$

All the activations are transformed to $expActivation\ (i) = e^{Activation(i).\mu}$ where *i* is the word of interest (past, present or future), and μ is the parameter indicating how rapidly the strength of the word *i* grows as a competitor with its increasing activation. Empirically, the consequence of the different levels of activation of past, present, future is reflected in the proportion of anticipation and perseveration errors. Following Luce's choice axiom, the probability of selecting a word is proportional to the ratio of that word's activation to the sum of activation of all words competing for selection (Equation 4):

$$P(i) = \frac{expActivation\ (i)}{\sum_{1}^{j} expActivation\ (j)} \qquad (4)$$

where *j* is the total number of words in the sequence[1]. Thus, the higher the activation of the past relative to the total activation, the higher the chance of its selection, which would manifest as a perseveration error. The same goes for present and future, manifesting as correct responses and anticipation errors respectively.

Three hypotheses about the influence of attention are tested:

1) Attention helps inhibit the past (*c*↓).
2) Attention helps activate the present (*k*↑).
3) Attention decreases the activation of future (*b*↓).

[1] The fourth word in the sequence was given a constant small amount of activation (0.01) and was included in the denominator as a potential, but weak, competitor.

Note that we only considered hypotheses that were compatible with the main finding of Nozari and Dell (2012), namely that increased attention should increase accuracy of the attended word. For example, we did not test increased priming of future, because it would have meant less accuracy on the attended word, as strong future priming increases the chance of the future word to be produced in place of the present word.

Two experiments are reported. Experiment 1 investigates the effects of selective attention on the pattern of anticipation and perseverations on the attended word itself. Experiment 2 studies the consequence of selectively attending to a word on errors on the word immediately following the attended word.

Experiment 1

Methods

Empirical data

Data were re-analyzed from sixty individuals who had participated in Experiments 1 and 2 in Nozari and Dell (2012). Participants were exposed to 64 four-word tongue-twisters, such as "wrist wing whiff rink". In the control condition, they rehearsed the tongue-twisters four times at the rate of 2 words/s, and then produced them four times from memory at the rate of 3 words/s. In the experimental condition, one of the four words (each position equally likely) was printed in bold and was underlined during the rehearsal phase. This was the attended word. Experiment 1 instructed participants to especially avoid making errors on

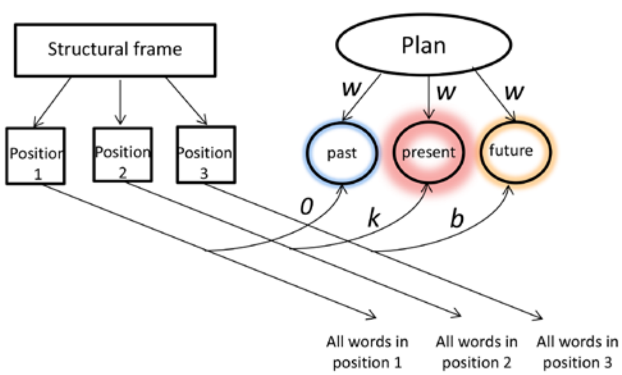

Figure 1. The architecture of the model with its two components and the relevant parameters that affect activation of each word. In this example, it is time to produce a word in position 2. Past retains a little bit of activation but it gets no support from the frame. The future gets a little bit of support for priming.

this word, while trying to be as error-free as possible throughout the sequence. Experiment 2 instructed participants to explicitly emphasize the word. As explained in the Introduction, both manipulations resulted in fewer errors on the attended word and more errors on the other words (unattended) in comparison to the control condition where no word was attended. Specifically, the error rate on the attended word in the experimental condition (e.g., "wrist ***wing*** whiff rink") were compared to that on the word in the similar position in a sibling tongue-twister (e.g., "mist *wing* whiff mink") in the control condition (the appearance of sibling tongue-twisters in the experimental and control conditions was counterbalanced across participants). The control word in the latter will be referred to as the "attended" to distinguish it from the three other words in the sequence, although in reality there was no difference between the four words in the control sequences.

For the purpose of the current study, the data were re-coded for anticipation and perseveration errors. A graduate student with linguistics background, trained in speech error coding, coded the errors according to the rules in Dell et al. (1997), and the coding was double-checked by the first author. Six categories of errors were coded: Word Anticipation (WA), Word Perseveration (WP), Sound Anticipation (SA), Sound Perseveration (SP), Exchanges (E), and Others (O). Errors were coded only on words in positions 2 and 3, because these were the only positions for which both anticipation and perseveration were possible. Anticipations were coded as producing whole (WA) or parts (SA) of upcoming words in place of the present utterance. For example, if participant produced "wrist wing *wink* rink" instead of the target sequence "wrist wing whiff rink", the error "wink" would receive the SA code. Conversely, if whole (WP) or parts (SP) of the words that had already been spoken re-appeared in the present utterance, a perseveration error was coded. For example, the error "wist" in "wrist *wist* whiff rink" would receive the SP code. Some errors had ambiguous origins, such as "ring" in "wrist *ring* whiff rink", which may be a perseveration from the /r/ in "wrist", or an anticipation of the /r/ in "rink". These errors were coded as Others and were not included in the analyses. Exchanges (e.g., "wrist *whiff wing* rink") were also excluded, as they contributed equally to anticipation and perseveration errors if they were to be counted as such.

Table 1- Error counts on the attended word (collapsed over words 2 and 3, and the two experiments). A = Anticipation; P = Perseveration; E = Exchange. W = Word; S = Sound; Exp = Experimental; Cont = Control. See text for definition of error types. The columns in bold are used in the analyses.

	WA	SA	**TotalA**	WP	SP	**TotalP**	TotalE	Others
Exp	9	46	**55**	3	18	**21**	63	19
Cont	26	47	**73**	8	25	**33**	65	16

Table 1 shows the number of each error type on the attended words collapsed across positions 2 and 3 for the experimental and control conditions. To have enough statistical power for comparing anticipations and perseverations, word and sound errors were combined. The upper left panel in Figure 2 shows error proportions on the attended word for anticipation and perseveration errors in control and experimental conditions. Proportions were calculated by dividing the raw error counts by the total opportunities for error on each word. Given the overall decrease in error probability on the attended word in the experimental condition reported by Nozari and Dell (2012), we tested the competing hypotheses of no change or a reliable decrease of anticipations, perseverations or both. Attention led to a significant decrease in perseveration errors ($t(59) = 1.79$, $p = 0.039$) and a marginal decrease in anticipations ($t(59)$, $p = 0.051$). Next we use the model to develop competing accounts of what attention does, and compare those accounts to the empirical data.

Simulations

Simulating performance in the control condition (the baseline model). Before different hypotheses were tested, a baseline model was needed to capture the data pattern in the control condition without manipulation of attention. A model with the following parameters well captured this pattern $w = 0.5$, $d = 0.5$, $c = 0.45$, $b = 0.35$, $k = 1$, $n = 3$, and $\mu = 10$ The parameters of the baseline model were then kept constant across the three simulations, except for a single parameter in each simulation that attention was hypothesized to influence. This parameter was changed to simulate the change to error proportions between the control and experimental conditions.

Model 1- Increased inhibition of the past. According to this hypothesis, attention acts by strongly inhibiting the past word, hence decreasing the probability of perseverations on the present (attended) word. The residual activation of the past after suppression is captured by parameter c in the model. We decreased c to a level where the model's predicted proportion of perseverations in the attended condition matched the empirical data. The critical test of the model's performance then comes from its prediction about the anticipations given the same parameters. This model predicted a slight increase in the proportion of anticipation errors from 7.6% to 7.7% (Figure 2, top right panel).

Model 2 – Increased activation of the present. This model tested the hypothesis that attention enhances the activation of the present but does not directly affect the activation of the past or the future. To simulate this, parameter k was increased to the level that the model would accurately capture the rate of perseveration errors. The test of the model was its prediction of the rate of Anticipations given the same set of parameters. The model predicted a drop from 7.6% to 4.6% in the rate of these errors (Figure 2, bottom left corner).

Model 3 – Decreased priming of the future. Perhaps attention works by preventing the speaker from focusing too far ahead. This hypothesis was tested by decreasing b. Once a level b was determined that best captured the rate of anticipation errors, the model's performance was evaluated by determining its estimated rate of perseverations. The model predicted a slight increase from 3.6% to 3.7% in the rate of perseverations (Figure 2, bottom right panel).

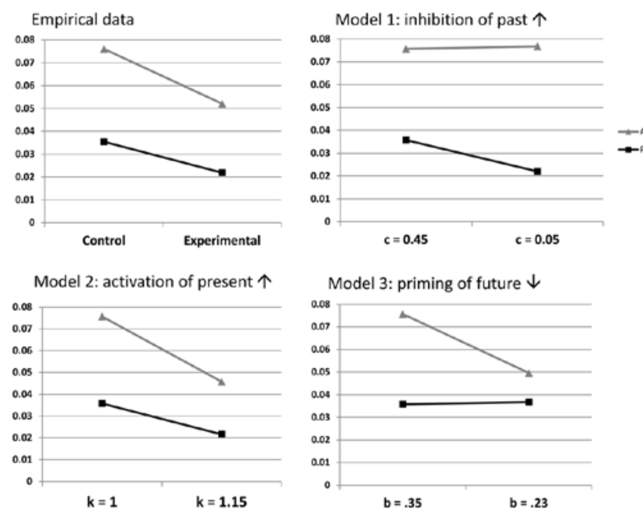

Figure 2 – The empirical data (top-left) and the three simulated models of the effect of selective attention on the proportion of Anticipation (A) and Perseveration (P) errors on the attended word in the experimental and control conditions.

Results and Discussion

Our empirical data revealed a decrease in the rates of both perseverations and anticipations on the attended words. Models 1 and 3, which tested the effects of attention on past and future respectively, each captured a drop in only one error type, but predicted no decrease in the other error type. If anything, a slight increase was predicted as a function of the lower competition from the other error type that was decreased (smaller denominator in Equation 4). The only model that captured the drop in both anticipation and perseveration errors was model 2 in which attention was hypothesized to only affect the activation of the present and not that of the past or the future. When tuned to mimic the perseveration rate on the attended word in the empirical data, this model predicts a drop of 3% in anticipation errors on that word. The actual data showed a comparable 2.4% drop. It thus seems that the effect of attention is best captured by a model that narrows the focus of attention to the object being currently processed, the result of which is a decrease in the processing of both the past and future.

Experiment 2

Experiment 1 supported a model in which selective attention was implemented by enhancing the activation of the present. We implemented this by increasing the connection weight between the present slot in the structural frame and the word to be currently produced. This implementation results in a transient effect. When the word is linked to the "present" slot in the frame its activation is boosted. As soon as it loses that link and becomes the past, it has no advantage over another word that was not boosted. If this characterization is correct, then the attended word, or its segments, should be no more likely to infiltrate the production of other words in the sequence.

Nozari and Dell (2012) presented a preliminary analysis of origin for errors on the unattended words that supported the contention that the segments from the attended words were not more likely to migrate to the unattended words. However, they included all errors (anticipatory errors, perseveratory errors, and exchanges) in counting errors whose origin was the attended word. Also, they included every error whose origin could potentially be the attended word in the analysis. The current experiment tested a more specific hypothesis predicted by the model that provided the best fit to the error data on attended words. Specifically, the model predicts no increase in the proportion of perseveration errors on the words following the attended word. The strongest demonstration of this should be on the word that immediately follows the attended word, because even if the attended word has retained any of its extra activation, this activation would decay over time, weakening its effect as more words are produced.

Methods

The same set of data from Experiment 1 was used for new coding and analyses. This time, we were interested in the effect that attending to a word had on the words after the attended word. The same attended words as Experiment 1 (words 2 and 3) were targeted, and the words immediately after them (words 3 and 4 respectively) were analyzed. Two types of perseveration errors were coded: (a) perseveration errors originating from the attended word; for example, the error "riff" in "wrist wing **whiff** *riff*" for the target "wrist wing **whiff** rink" would be coded as a perseveration originating from the attended word. We call these AttOrg+ errors. The second class were (b) perseveration errors originating from the unattended word(s), for example, the error "ring" in "wrist wing **whiff** *ring*" would be coded as a perseveration originating from an unattended word. We call these AttOrg− errors. Similar to Experiment 1, errors with ambiguous origin were not included in the analyses.

Results and Discussion

In the experimental condition, there were 63 AttOrg+ and 31 AttOrg− perseveration errors. In the control condition, there were 73 AttOrg+ and 21 AttOrg− perseveration errors. Figure 3 shows the proportion of errors relative to opportunities. As can be seen, there was no evidence for more perseverations from the attended word onto the next word in the experimental than the control condition. If anything, there were numerically fewer such errors, although the difference was not reliable (t(59) = 0.24 using a two-tailed t-test on the error counts).

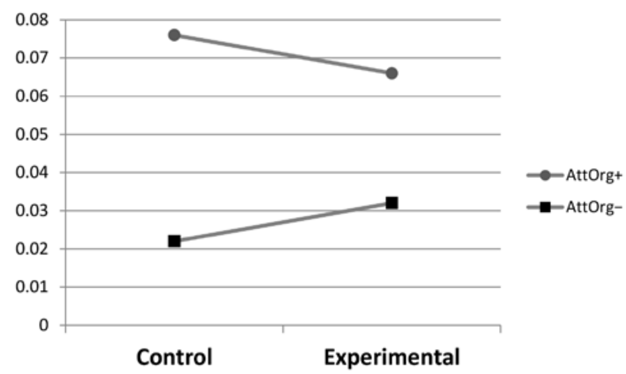

Figure 3- Proportion of AttOrg+ and AttOrg− perseveration errors on the word immediately after the attended word (collapsed over words 3 and 4), in the experimental and control conditions.

Perhaps there are simply fewer perseveration errors on words after the attended word in the experimental condition, and this decrease does not really reflect anything about the source of those errors. To test this, we compare this pattern to the perseveration errors on the same words that originate from the unattended words in the sequence. This was done by looking at the difference between the AttOrg+ and AttOrg− errors in the experimental and control conditions (equivalent to an interaction analysis). A marginally significant interaction between the pattern of errors was found (t(59) = 0.06 using a two-tailed t-test). This shows that the drop in the perseverations from the control to the experimental condition is particular to the AttOrg+ errors.

General Discussion

In previous work, we had demonstrated that selectively attending to one out of four words in a sequence increases accuracy on that word, while decreasing accuracy on the other words (Nozari & Dell, 2012). In this study, we presented model-driven analyses of the error data, and three simulations, in which attention was manipulated by (1) more strongly suppressing the past, (2) more strongly activating the present, and (3) less strongly priming the future. Experiment 1 showed that the pattern of anticipation and perseveration errors on the attended word itself was most compatible with the model in which attention influenced the activation of the present (simulation 2). Experiment 2 tested a further prediction of such a model, by looking at the pattern of perseverations, this time on the word following the attended word. If attention exerts a transient influence on the present, as modeled in simulation 2 through a link to the structural frame, then there should be no increase in the probability of the attended word to intrude in the production of the following word.

In agreement with the results of Nozari and Dell (2012), the current analysis found no evidence of increased perseveration errors from a word that was previously in the focus of attention on the word that was to be presently produced. A follow-up analysis showed that this was not due to a general drop in the perseveration errors on the words following the attended word, but was a pattern specific to those originating from the attended word itself. Together, these results support a model in which attention is implemented in the connections between the present slot in a structural frame and the word to be presently spoken.

We close by briefly discussing one angle from which these data can have a clinical impact. Perseveration errors are common in individuals with brain damage (e.g., Albert & Sandson, 1986; Fischer-Baum & Rapp, 2012), children (e.g., Stemberger, 1989), and older adults (Foldi, Helm-Estabrooks, Redfield, & Nickel, 2003). These are also populations that usually have impaired cognitive control. Often though, perseveration errors are viewed as related to cognitive control if the problem is connected to suppression of the past. While inhibition of the past is the cause of perseverations for some individuals, Perseverations in others have been shown to be due to insufficient activation of the present (Fischer-Baum & Rapp, 2012). If selective attention works by specifically enhancing the activation of the present, methods that train selective attention might be the key to abolishing perseveration errors in clinical populations.

Acknowledgments

This work was supported by the Therapeutic Cognitive Neuroscience Fund awarded to N. Nozari and B. Gordon.

References

Albert, M. L., & Sandson, J. (1986). Perseveration in aphasia. *Cortex*, *22*(1), 103–115.

Bock, K., Irwin, D. E., & Davidson, D. J. (2004). Putting first things first. In F. Ferreira & J. Henderson (Eds.), The integration of language, vision, and action: Eye movements and the visual world (pp. 249–278). New York, NY: Psychology Press.

Dell, G. S., Burger, L. K., & Svec, W. R. (1997). Language production and serial order: A functional analysis and a model. *Psychological Review*, *104*(1), 123.

Fischer-Baum, S., & Rapp, B. (2012). Underlying cause (s) of letter perseveration errors. *Neuropsychologia*, *50*(2), 305–318.

Foldi, N. S., Helm-Estabrooks, N., Redfield, J., & Nickel, D. G. (2003). Perseveration in normal aging: A comparison of perseveration rates on design fluency and verbal generative tasks. *Aging, Neuropsychology, and Cognition*, *10*(4), 268–280.

Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: bridging selective attention and working memory. *Trends in Cognitive Sciences*, *16*(2), 129–135.

Gleitman, L. R., January, D., Nappa, R., & Trueswell, J. C. (2007). On the give and take between event apprehension and utterance formulation. *Journal of Memory and Language*, *57*(4), 544–569.

Griffin, Z. M., & Bock, K. (2000). What the eyes say about speaking. *Psychological Science*, *11*(4), 274–279.

Kuchinsky, S. E., Bock, K., & Irwin, D. E. (2011). Reversing the hands of time: changing the mapping from seeing to saying. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(3), 748.

Nozari, N., & Dell, G. S. (2012). Feature migration in time: Reflection of selective attention on speech errors. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(4), 1084.

Nozari, N., & Thompson-Schill, S. L. (2013). More attention when speaking: Does it help or does it hurt? *Neuropsychologia*, *51*(13), 2770–2780.

Oppenheim, G. M., Dell, G. S., & Schwartz, M. F. (2010). The dark side of incremental learning: A model of cumulative semantic interference during lexical access in speech production. *Cognition*, *114*(2), 227–252.

Oppermann, F., Jescheniak, J. D., & Görges, F. (2013). Resolving competition when naming an object in a multiple-object display. *Psychonomic Bulletin & Review*, 1–7.

Piai, V., Roelofs, A., & Schriefers, H. (2012). Distractor strength and selective attention in picture-naming performance. *Memory & Cognition*, *40*(4), 614–627.

Stemberger, J. P. (1989). Speech errors in early child language production. *Journal of Memory and Language*, *28*(2), 164–188.

Tomlin, R. S. (1997). Mapping conceptual representations into linguistic representations: The role of attention in grammar. In J. Nuyts & E. Pederson (Eds.), Language and conceptualization (pp. 162–189). Cambridge, England: Cambridge University Press.