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Feature Migration in Time: Reflection of Selective Attention on Speech Errors

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Abstract

This paper describes an initial study of the effect of focused attention on phonological speech errors. In three experiments, participants recited four-word tongue-twisters, and focused attention on one (or none) of the words. The attended word was singled out differently in each experiment; participants were under instructions to either avoid errors on the attended word, to stress it, or to say it silently. The experiments showed that all methods of attending to a word decreased errors on that word, while increasing errors on the surrounding words. However, this error increase did not result from a relative increase in phonemic migrations originating from the attended word. This pattern is inconsistent with conceptualizing attention either as higher activation of the attended word or greater inhibition of the unattended words throughout the production of the sequence. Instead, it is consistent with a model which presumes that attention exerts its effect at the time of production of the attended word, without lingering effects on the past or the future.

Keywords

Speech errors; Attention; Phoneme migration; Cognitive control

Introduction

A hallmark of human cognition is that it is error prone. We have mechanisms to detect and correct errors once they happen, but ideally, we would rather they did not happen in the first place. That is why we *pay attention*. One means by which paying attention increases accuracy is preventing “feature migrations” (Triesman & Gelade, 1980). If an observer’s attention is engaged elsewhere while viewing a scene containing a green X and a red O, s/he might report having seen a red X, meaning that the color feature has migrated from one object to another. The probability of such immigrations can be lowered by focusing attention on the green X by, say, precuing its location, even when the overall difficulty of the task matches cases in which the object has not been precued (Treisman & Schmidt, 1982).

Feature migrations occur in reading as well, with objects and features corresponding to words and letters, respectively (e.g. Allport, 1977; McClelland & Mozer, 1986; Mozer, 1983; Shallice & Warrington, 1977). A pathologically high degree of such errors

characterizes *attentional dyslexia* (e.g. Davis & Colthart, 2002; Friedmann, Kerbel, & Shvimer, 2010; Humphreys & Mayall, 2001; Saffran & Coslett, 1996), a disorder in which the high rate of letter migration between written words makes reading very difficult to impossible. The problem can be easily remedied by the use of a moving window, about the size of a single word, which provides a narrow focus for attention.

Features not only move in space during perception, they also move in time during production. This is what happens in speech errors. Parts of words (e.g. phonemes) move from one planned word to another (e.g. Fromkin, 1971), creating slips such as “shoving leopard” for “loving shepherd”. It is in fact possible that the *naming-in-context* aphasic disorder (e.g. Schwartz & Hodgson, 2002) is the analogue of attentional dyslexia in speech production. Patients affected by this disorder have trouble naming pictures in a sequence, but as soon as the production window is limited to one word, by covering or removing other pictures, the problem disappears.

Attention therefore seems to play an important role in the perception and production of spatial and temporal word sequences. Few attention studies have specifically concerned production though, and most of these studies have investigated linguistic choices as a function of visual attention manipulation (e.g. Nappa et al., 2004; Tomlin 1995) or speaker/listener distraction (Rosa & Arnold, 2011), or have looked at eye movements to pictured objects during speaking (e.g. Griffin & Bock, 2000). Specifically, what has not been studied before—and is studied here—are the consequences of attending differentially to various parts of the utterance. Moreover, most production models make no mention of attention (with the notable exception of models dealing mainly with single-word production, e.g. Roelofs, 2003), and to our knowledge, no speech-error models have mechanisms that simulate attentional effects.

We believe that much can be gained if the study of language production in general, and speech-error models in particular, would take note of the influence of selective attention. But to integrate attentional processes into these models, one must first answer an empirical question: If attention is focused on one word in a multi-word utterance, what are the consequences for error on that word, and perhaps more importantly, the other words in the utterance? This question can be answered by analyzing speech errors under conditions where participants do or do not focus on one word in a sequence. Such data can then begin to address the theoretical issue of what happens at the cognitive level when attention is directed to a part of an utterance. An important approach to attention, the dual-mechanism framework (e.g. Braver, Reynolds, & Donaldson, 2003), distinguishes between sustained and transient cognitive control. In our experiments, transient control concerns what happens just at the time that a focused word is produced. Perhaps the most intuitive approach to this issue is to propose that an attended word would be more “activated”. In computational models of speech production, a word is enabled for production by giving its lexical representation (its lexical node) a large jolt of activation (e.g. Dell, 1986; Dell, Burger, & Svec, 1997). It is then straightforward to assume that an attended word would receive a greater jolt. If after receiving the jolt the attended word’s node follows the same activation dynamics as other nodes, it will tend to possess a relatively higher activation throughout its preparation and production, and a higher residual activation after it is produced. This leads to an empirical prediction: there should be relatively more migrations of phonemes from an attended word to surrounding words. The other kind of attentional control, sustained (or state-related) control, concerns the general cost of maintaining a cognitive operation to be performed throughout a task block, in our case, producing utterances that contain a focused word. In the condition in which no word is focused, though, there is no need for such control. Thus, there could be costs in terms of increased error rates on all words when a word from each utterance is focused compared to conditions in which nothing is focused.

To address the issues raised above, three experiments are reported in which speech errors are elicited as participants recite four-word tongue-twisters, one (or none) of which is being attended. In Experiment 1, participants are directly instructed to avoid mistakes on a particular word. In Experiment 2 attention is directed at a certain word by requiring participants to stress that word. Finally, in Experiment 3 participants are required to *mouth* (silently recite) one of the four words; thus the physical manifestation of attention is the opposite of the stress instruction given in Experiment 2. To answer the first question raised earlier about the empirical effects of attention, we first compare the error rates when participants do and do not focus attention on a certain word. Then, for each experiment, we perform a migration analysis, specifically addressing the question of whether attending to a word makes that word's constituents more likely to migrate to the other words in the utterance. We conclude by considering the theoretical implications of the data.

Experiment 1

Methods

Participants—32 undergraduate students at the University of Illinois at Urbana-Champaign participated for course credit.

Materials—32 pairs of tongue-twisters (total = 64) were borrowed from Oppenheim and Dell (2008). Each tongue-twister consisted of four words with the same vowels and an XYYX onset pattern (e.g., “just rum rug jump”). In the experimental condition, one of the four words in the tongue twister was printed in bold and was underlined (e.g., “just rum **rug** jump”). Each of the four words was so marked with equal probability across participants. The control condition contained tongue-twisters with the same structure but with no bold and underlined words. For each tongue-twister in the experimental condition, there was a sibling tongue-twister in the control condition (e.g., “lust rum rug lump”), and presentation of the sibling tongue-twisters in the experimental vs. control condition was counterbalanced.

Procedure—Participants completed four test blocks (two experimental, two control), with short breaks between the blocks belonging to the same condition and a longer break when condition was switched and a new set of instructions was delivered. The experiment was run in MATLAB and half the subjects completed the experimental blocks first, while the other half, the control blocks first. In the control condition, a single trial consisted, first, of a familiarization display, where the four words appeared on a computer screen and the participant was asked to enunciate each word carefully. Necessary corrections were made by the experimenter until the participant successfully pronounced all four words. Next, a rehearsal phase began, in which the same four words appeared on the screen and a metronome played at 2 beats/sec. For four beats, the participant only listened. At the beginning of the fifth beat, a red dot appeared under each word, and moved to the next word at the pace of the metronome. Participants were to read the words aloud as the red dot moved along. They then listened for the next four beats (without the red dot) and began reciting on the fifth as the red dot reappeared. Four rehearsal cycles were completed in each trial. No errors were registered at this phase. If the participant repeatedly made an error, the experimenter corrected the error and had them repeat the rehearsal phase of that trial from the beginning (this was seldom required).

Finally, the test phase began. Like the rehearsal phase, there were four cycles, each containing a silent part in which the participants just listened to the metronome for four beats and a speaking-aloud part, in which they had to say the words aloud at the pace of the metronome, and along with the visual cue (the red dot). There were two differences between the rehearsal and the test phase though: first, the pace of the metronome was higher in the test phase (3 beats/sec), and second, the words were no longer printed in the center of the

screen. In the silent part of each cycle, the words appeared in a small font in gray color at the top of the screen. Participants were encouraged to repeat the words from memory, but were allowed to consult them if they could not remember them. In the speaking aloud part of the cycle, the words disappeared and the red dot appeared at the place previously occupied by the printed words in the center of the screen in the rehearsal phase. As the dot moved from position 1 to 2 to 3 to 4, along with the metronome beat, the participant had to say the words aloud. They were told to try to repeat the words as accurately as possible on the metronome beat. After receiving the instructions, participants completed a short practice block of eight trials. If the experimenter judged their performance with regard to following the general instructions to be unsatisfactory at the end of the practice block, they were run through that block again.

The experimental condition was very similar, with the exception that one of the words was bold and underlined as soon as the participants reached the rehearsal phase. They were instructed to try to be accurate overall, but to especially avoid making errors on the underlined word or else they would hear an annoying buzz (the experimenter who monitored their performance used the buzzer from the game Taboo). The relevant instructions were presented right before the participants started this condition and a practice block comprised eight trials preceded the test blocks. Similar to the control condition, participants did not start the test blocks unless satisfactory performance was achieved on the practice block.

During the study, an experimenter (the first author or a trained assistant) sat next to the participants. In the experimental condition, s/he buzzed the participants immediately if they made an error on the underlined word in the test phase. Responses were digitally recorded for offline transcription. Both the first author and the assistant transcribed errors from the recordings with an inter-rater reliability of 0.89 ($SE = 0.008$) calculated as Cohen's Kappa. In cases where the two transcriptions differed, the recording was replayed, and if the transcribers still disagreed, the utterance was not coded as an error.

Results and Discussion

One participant was excluded from this experiment for failing to follow instructions. There were thus a total of 15872 spoken words in each condition from the remaining 31 participants, each of which presents an opportunity for error. For participants who did follow the instructions, if they refrained from responding on 50% or more of the words in a trial during the test phase, that trial was excluded. After enforcing this criterion, data from four trials (64 error opportunities), all belonging to the experimental condition, were eliminated.

Errors consisted of substitution, addition, or deletion of phonemes, or, less often, substitution of entire words. 82% of all errors were within-trial migrations, meaning that a phoneme had moved from one word to another in the same trial, or alternatively, a word had moved to a different position in the trial. The remaining 18% of the errors were outside intrusions (e.g. “just *rub* rug jump” for the target “just rum rug jump”), distributed evenly between the experimental (51%) and control (49%) conditions. Of the within-trial migrations, 29% were word substitutions. This, however, might be an overestimation, because coding word substitutions was prioritized over phoneme substitutions. For example, the first *rug* in “just *rug* rug jump” for the target “just rum rug jump” was coded as a word substitution (there was an identical word in the target that now appeared in the wrong place), although theoretically it could have been a phoneme substitution. Because of this ambiguity, when we report migration rates, we lump phoneme and word migrations together.

In order to compare the experimental to the control condition, we assigned what we called “fake” attended status to words in the control condition. To this end, for each tongue-twister pair in the experimental condition, we found its paired tongue-twister in the control

condition and assigned the word in the same position to the fake attended status. In other words, we pretended that it had been underlined for purposes of analysis. For example, if “just rum rug jump” was in the experimental condition, “lust rum rug lump” was located in the control condition and “rug” was given the fake role of the attended word. From now on, we use the term “attended and unattended” for both experimental and control conditions, although in reality, fake attended words were not treated differently than fake unattended words by the participants.

A total of 804 errors (149 on the attended and 655 on the unattended words) were made in the experimental condition, and 716 errors (192 on the attended and 524 on the unattended words) in the control condition. Since the total opportunities for making errors differed, each number was turned into a proportion by dividing it by the total number of error opportunities a participant had in that condition for that word-status. Figure 1a (Nozari & Dell, 2011) shows these proportions. To examine how focusing attention on one word affects the processing of that word and the unattended words, we performed hierarchical binomial multiple regression in the statistical package R, using a mixed model which treated subjects and items as random effects. The final model (after testing for the necessity of each random effect) consisted of a fixed effect combining the two independent variables each with two levels (condition: experimental vs. control; word-status: attended vs. unattended) and random intercepts and slopes for this variable over both subjects and items. The construct of this model is optimal for testing the contrasts of interest reported below.

There were more errors overall in the experimental than the control condition, although this difference did not reach significance ($z = 1.65$, $p = .10$). However, the interaction between condition (control vs. experimental) and word-status (attended vs. unattended) was significant¹ ($z = -3.43$, $p < .001$). There were significantly more errors on the unattended compared to the attended words in the experimental condition ($z = 4.88$; $p < .001$), but no such difference was observed between the error rates on the (fake) attended and unattended words in the control condition ($z = -1.35$; $p = .18$). These results show that the experimental manipulation has been successful. They further allow us to use the average of the (fake) attended and unattended words in the control condition, as the baseline for comparison with the experimental condition. The following two contrasts address the important questions of what happens to the accuracy of the attended and the unattended words compared to a baseline of no selective attention. There were significantly fewer errors on the attended words compared to the baseline ($z = 3.063$; $p = .002$), and significantly more errors on the unattended words compared to the baseline ($z = -2.543$; $p = .010$)².

These results suggest that focusing on one word makes the production of that word more accurate at the cost of the accuracy of the surrounding words. But how should attention be implemented in a cognitive model of production? As we noted before, if greater attention means more activation and this activation is delivered much like the activation jolt in production models, we expect more migrations to originate from attended words. There will be more anticipation errors because the attended word's activation is boosted when it is the upcoming word, and there will be more perseveration errors because the boosted activation of the attended word leads to greater activation persistence when its production is over. So, there would be an increased migration rate from the attended word to the surrounding words both before and after the production of the attended word. We approached this question by looking at migrations from the attended –or the fake attended– to the unattended words. If

¹Wherever in this paper a significant effect is reported through a multilevel logistic model, it has been double-checked with the nonparametric Wilcoxon signed-rank test.

²In total 4 contrasts were tested across the four means, each of which used $\alpha = .05$ with a two-tailed test. Using a more conservative Bonferroni correction does not change any of the conclusions.

the error on an unattended word contained a phoneme or phonemes from the attended –or the fake attended- word, we labeled it as *AttOrg+*, otherwise, it was labeled as *AttOrg-*. For example, if instead of “just rum **rug** jump”, the participants had answered “*jug* rum rug jump”, the error “jug” was coded as an *AttOrg+* error, but if instead s/he had said “*jum*”, that would have been coded as *AttOrg-*.

Of the total errors made on the unattended words in the experimental condition, 32% of them were *AttOrg+*. This was not significantly different from the 31% *AttOrg+* errors on the unattended words in the control condition (see Figure 2a). We also checked for migrations from the attended word specifically when that word was itself mispronounced because theories of phoneme movement propose that error on an item may stimulate its phonemes to move elsewhere, creating errors on other words (e.g. Dell, 1986). So, we looked at the subset of data where participants had made an error on the attended word, and recalculated the proportion of *AttOrg+* errors on the unattended words for only those trials. The proportions were the same as before, hence, once again, there was no significant difference in terms of migration between the two conditions.

In summary, Experiment 1 showed that prioritizing one word decreases the probability of error on that word while increasing the error probability on the surrounding words. However, the attended word was not more likely to migrate, as a whole or as parts, to other locations in the sequence. To generalize these results, in Experiment 2 we asked participants to focus on a word by overtly stressing it, instead of making its correct production a priority.

Experiment 2

Methods

Participants—32 undergraduate students at the University of Illinois at Urbana-Champaign, who had not taken part in Experiment 1, participated in the study for course credit.

Materials—The materials from Experiment 1 were used.

Procedure—The procedure was the same as for Experiment 1, except for the instructions given for the experimental condition. Participants were told to *stress* the bold and underlined word when they pronounced it. An example was given: “John shot two ducks”, and the experimenter showed the participants how each word can be contrasted with other words by changing its pronunciation. During the rehearsal phase of the experiment any perceived increase in intensity, duration, pitch, or pitch range was accepted as successful stressing on the participant’s part. That is, there was no effort to create any specific acoustic enhancement.

Results and Discussion

The exclusion criteria of Experiment 1 were enforced here as well. In addition, if the participants could not follow the stressing instructions properly after completing the practice block twice, they were excluded. Two participants were thus eliminated. For the remainder of the participants, recitations during the test phase in which they did not stress the underlined word (as judged by the two independent transcribers) were thrown out. Overall, 336 error opportunities were excluded for the remaining 30 participants, all belonging to the experimental condition (<3% of error opportunities in this condition).

The same procedure as Experiment 1 was repeated to assign fake stressed status to words in the control condition. 1023 errors (189 on the stressed and 834 on the unstressed words) were made in the experimental, and 943 errors (258 on the stressed and 685 on the

unstressed words) in the control condition. Figure 1b shows the proportion of errors for each word-status in each condition. A similar type of hierarchical logistic regression model was used, and the same procedure described in Experiment 1 was repeated to decide which random effects to include. Findings of Experiment 1 were replicated: Although there were overall more errors in the experimental condition, this difference did not reach significance ($z = 1.48$, $p = .14$). However, the interaction between condition and word-status was significant ($z = -3.88$, $p < .001$). There were significantly more errors on the unattended compared to the attended words in the experimental condition ($z = 4.48$; $p < .001$), but no such difference was observed between the error rates on the (fake) attended and unattended words in the control condition ($z = -.20$; $p = .84$). A baseline was then calculated by averaging the error rates on the (fake) stressed and unstressed words in the control condition. This baseline was significantly higher than the error rate on the stressed words in the experimental condition ($z = 3.432$; $p < 0.001$), and significantly lower than that of the unstressed words ($z = -2.604$; $p = 0.009$).

We also repeated the migration analysis from Experiment 1. Of the total errors on the unattended words in the experimental condition, 32% of them were *AttOrg+*, and of those in the control condition, 41% (Figure 2b). When only those trials with mispronounced attended words were considered, the proportion of *AttOrg+* errors in the experimental condition remained the same, and that of the control condition increased to 42%. Neither difference was statistically significant. To summarize, Experiment 2 replicated the results of Experiment 1, in that when a word was singled out, that word was less error-prone, while the surrounding words were more error-prone. This, however, was not accompanied by more phoneme migrations from the attended word to other words. If anything, the pattern of results in Experiment 2 suggested the opposite.

It is possible that these findings are caused by the physical emphasis given to the attended word rather than to the act of attending to that word generally. In Experiment 3, we address this concern by asking participants to do the opposite of what they did in Experiment 2: to mouth (silently produce) one of the four words.

Experiment 3

Methods

Participants—39 undergraduate students at the University of Illinois at Urbana-Champaign, who had not taken part in Experiments 1 or 2, participated in the study for course credit.

Materials—The same materials as before were used.

Procedure—The procedure was the same except for the instructions in the experimental condition. Participants were instructed to mouth the bold and underlined word, meaning that they had to make the gesture of saying the word with their mouth, without producing sounds.

Results and Discussion

The exclusion criteria were similar to Experiment 2, except that mouthing, instead of stressing, was the requirement by which performance was judged. This procedure proved to be more difficult than the other two, and four participants could not follow the mouthing instructions even after going through the practice block twice. Moreover, there were many more silences in the control condition especially for participants who had first completed the mouthing condition, which led to the elimination of 7 trials (112 error opportunities) in this

condition, over the remaining 35 participants. Silence or failure to properly mouth the word also led to the elimination of 271 error opportunities in the experimental condition.

Words were assigned to the fake mouthed status in the control condition in the fashion described for the other two experiments. Participants made 969 errors on the articulated words in the experimental condition and 832 in the control condition. Figure 1c shows the proportion of errors to the total error opportunities for each word-status in each condition. Note that there is no bar for the errors on the mouthed words in the experimental condition, because by definition, these words were not supposed to be pronounced aloud (that recitation was excluded if they were), and therefore, there was no objective criterion by which accuracy could be judged. But the important comparison is between the proportion of errors on the articulated words in the experimental and control conditions, which was assessed using a hierarchical logistic model as before. There were significantly more errors on the articulated words in the experimental than the control condition ($z = 2.19$; $p = .029$).

When the errors on the unattended (articulated) words were compared for their origin, there was no significant difference between the experimental and control conditions, with both showing 40% *AttOrg+* errors (Figure 3c. Note that here we cannot choose a subset of trials in which an error had occurred on the attended (mouthed) word in the experimental condition). In summary, Experiment 3 replicated the results of the previous experiments by confirming that attending to one word does in fact increase errors on the unattended words without increasing the relative phonemic migration from the attended word.

General Discussion

The study of speech errors has contributed significantly to our understanding of language production, and models of speech errors have simulated many aspects of normal and pathological language processing (e.g. Nozari, Kittredge, Dell, & Schwartz, 2010). Speech errors can also be used to study the interaction between the production system and other systems, such as the executive system. This paper takes a first step, by examining selective attention in multi-word utterances. We reported three experiments, in which participants recited tongue-twisters with one or none of the words singled out. In Experiment 1 this was achieved by instructing participants to avoid errors on a specified word. In Experiment 2 selective attention was recruited by instructions to stress a certain word, and in Experiment 3, the reverse (mouthing) strategy was used to single out a word.

Three results were obtained: (1) When attention is focused on one word in a sequence, the accuracy of the other words suffers, but (2) the attended word itself is produced *more* accurately. However, (3) the more accurate production of the attended word is not accompanied by more migrations from that word to the unattended words. These results sit nicely within the dual-mechanism framework of cognitive control which proposes separate sustained and transient control mechanisms (Braver et al., 2003). With regard to sustained control, our participants must maintain two different statuses (attended vs. unattended) for different words throughout the experimental block, but only one status throughout the control block. There is thus higher demand for sustained control in the experimental condition which, if not met, could lead to higher error rates in this condition, explaining the higher error rates on the unattended words in the experimental blocks.

But why doesn't the attended word show higher error rates, even though it is produced in the experimental condition which is associated with higher demand for sustained control? Because in the dual-mechanism framework, there is a second type of cognitive control, the transient control mechanism, which operates at the level of individual items. Our results show that selectively attending to one word in a sequence successfully recruits transient control, thus decreasing error rates on the attended word. This claim is further supported by

the absence of increased migrations from the attended word to the surrounding words, since the control mechanism responsible for the effect is truly transient and does not persist beyond the production of the attended word. In the remainder of this section, we propose a specific mechanism for how transient cognitive control may be implemented in a language production model.

Production theories distinguish between the *present* (the word being currently produced), the *past* (the word/words just produced) and the *future* (the word to be produced next). In all speech-error models, the *present* is given a large jolt of activation, the *future* is given a small jolt to prime it, and the *past* is inhibited in an attempt to reduce its activation (Dell, 1986; Dell et al., 1997; MacKay, 1987). As we stated earlier, the most natural implementation of attention is by giving the attended word greater jolts. This would explain its more accurate production, but it would also predict more migrations from the attended word to the other words because it is also more activated when it is past (less inhibited) or future (more primed). A similar prediction would be made by general inhibition of the unattended words throughout the production of the sequence. Our results do not support either the greater jolt to the attended or the greater inhibition of the unattended. There was no tendency for a greater migratory proportion from the attended word in the experimental condition compared to that from the (fake) attended word in the control condition. If anything, the results of Experiment 2 suggested the opposite.

The results thus point to a model in which the effect of increased cognitive control on the attended word is limited to the window of *present*, such that the attended word's activation is given an additional jolt only when it is *present*, and that the effect of this additional jolt is eliminated as soon as the word becomes *past*. We propose that this is compatible with implementation of attention in the "sequencing" frame. The sequencing frame (e.g. Gordon & Dell, 2003) is an integral part of any multi-word production model. The frame encodes the general properties of the sequence (e.g. for our experiments, that there are four words, or for an actual grammatical sentence, that it has, say, a direct object and a prepositional phrase). It directs activation to words in the sequence with the goal of turning on a word when it is *present* and turning it off when it becomes *past*. Given this and our findings regarding migration errors, it is most parsimonious to assume that attention only increases the activation of the *present* slot in the sequencing frame, which is then effectively reduced to baseline by inhibitory processes that the frame normally uses on a word once it becomes *past*. In this way, variation in how the sequencing frame sends activation to particular words, as a function of whether a word is attended or unattended, is a form of transient cognitive control.

In summary, our three experiments suggest that focusing attention on one word increases the error rate on other words in the sequence, which is best explained by the sustained cost of tracking the different statuses of the attended and the unattended words. As for the attended word, it is produced with greater accuracy, but without its phonemes migrating more often to the unattended words. The latter two findings are explained by a transient cognitive control mechanism, which can be located in the sequencing frames proposed in speech production models.

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Figure 1.

(a–c). Proportion of errors for each word-status (attended vs. unattended, stressed vs. unstressed, mouthed vs. articulated) in the experimental and control conditions in Experiments 1(a), 2 (b) and 3 (c).

Figure 2.
(a–c). Proportion of AttOrg+ errors to all errors made on the unattended words in Experiments 1 (a), 2 (b) and 3 (c).