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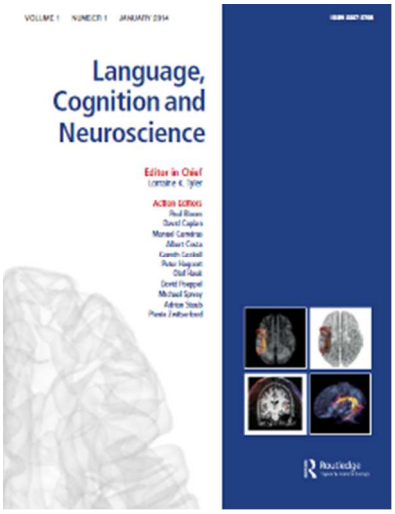

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Interactions between Lexical Access and Articulation

Angela Fink[a], Gary M. Oppenheim[bcd], and Matthew Goldrick[a*]

[a] Northwestern University, Department of Linguistics, Northwestern University, 2016 Sheridan Rd., Evanston, IL 60626; afink@u.northwestern.edu; matt-goldrick@northwestern.edu
[b] Bangor University, School of Psychology, Adeilad Brigantia, Penrallt Road, Bangor, Gwynedd LL57 2AS, UK; g.m.oppenheim@bangor.ac.uk
[c] Rice University, Department of Psychology, Houston, TX 77251
[d] University of California San Diego, Center for Research in Language, 9500 Gilman Dr, La Jolla, CA 92037
*Corresponding author; +1-847-491-8053

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Abstract

This study investigates the interaction of lexical access and articulation in spoken word production, examining two dimensions along which theories vary. First, does articulatory variation reflect a fixed plan, or do lexical access-articulatory interactions continue after response initiation? Second, to what extent are interactive mechanisms hard-wired properties of the production system, as opposed to flexible? In two picture-naming experiments, we used semantic neighbor manipulations to induce lexical and conceptual co-activation. Our results provide evidence for multiple sources of interaction, both before and after response initiation. While interactive effects can vary across participants, we do not find strong evidence of variation of effects within individuals, suggesting that these interactions are relatively fixed features of each individual's production system.

Keywords: language production, lexical access, articulation, interaction

Interactions between Lexical Access and Articulation

Theories of spoken word production assume that several broad stages of post-semantic processing underlie the planning and execution of speech (Garrett, 1980; Levelt, 1989). Lexical access—the retrieval of lexical and phonological representations from memory—bridges conceptual and word form representations. These word form representations are then used to generate a detailed articulatory plan, which the motor system then executes.

Although these stages have often been characterized as serial and discrete, recent production research has demonstrated that many factors that influence lexical access can also modulate the phonetic properties of the word that is ultimately produced. That is, the same sequence of speech sounds can be pronounced in many different ways, for instance changing their duration, pitch, and intensity without actually changing the word that they denote. Such phonetic properties can reflect not only general speech style (Aylett & Turk, 2004; Baker & Bradlow, 2009) and the structure of the articulatory plan, but also the influence of factors that make selecting a particular lexical item to express a concept (lexical selection) relatively easy or difficult. These factors include contextual predictability (*court* is highly predictable following *supreme;* Bell et al., 2009), informativity (*nowadays* is more informative than *current* because it is unpredictable in any context; Seyfarth, 2014), and givenness (whether a referent has been used previously in a discourse; Fowler & Housum, 1987; Kahn & Arnold, 2012; 2015; Lam & Watson, 2014).

One prominent explanation for such phonetic manifestations of conceptual and lexical effects assumes that lexical access and articulatory processes interact. This interaction can take many forms – which need not be mutually exclusive (e.g., Goldrick,

Baker, Murphy, & Baese-Berk, 2011) – including mechanisms that: a.) coordinate the relative timing of these two processes (Bell et al., 2009); b.) vary articulatory precision/prominence based on the activation of target (Kahn & Arnold, 2012; Lam & Watson, 2014); c.) allow partially active competitor representations to activate articulatory plans (Goldrick & Blumstein, 2006); and/or d.) incorporate articulatory details into stored lexical access representations (Goldinger, 1998; Pierrehumbert, 2002).[1]

While these interactive accounts allow crosstalk between lexical access and articulation, they generally assume that lexical access is a ballistic process (Logan & Cowan, 1984; Navarette, Del Prato, Peressotti, & Mahon, 2014), encapsulated from other components of the cognitive system. Under these 'planning-drives-articulation' accounts (see Buz & Jaeger, 2015, for discussion), an articulatory plan develops up until some point at or before the initiation of a motor response, and cannot be changed or disrupted after that time – neglecting the possibility that input patterns could continue to develop after response initiation. For instance, a completed articulatory plan might reflect the state of the planning network at the moment of response initiation, encoding the relative activation of the target word (e.g., CAT) as well as the coactivation of non-target representations (BAT and RAT). Under a ballistic account, these levels of co-activation would then remain fixed throughout execution of the plan. Additionally, if planning representations are not abstract, but highly detailed, the plan could specify the stored phonetic properties of diverse exemplars ('cat' with a long vowel and heavy release of /t/ vs. a short vowel and unreleased stop). Under such accounts, the extent of lexical effects on phonetic variation

[1] Note that interactive mechanisms are not the only level of analysis at which such effects can be explained; in the general discussion, we consider the relationship between such accounts and those based on communicative goals.

specifically depends the state of lexical access at the moment when articulation begins. Such mechanisms therefore predict a fixed relationship between planning measures (e.g., picture-naming latencies) and articulatory measures (e.g., spoken word durations): wherever these levels interact, they should always interact, and interact to the same degree.

Though such an assumption conveniently constrains the scope of language planning models, production cannot entirely fit within that 'ballistic' characterization. For instance, Levelt (1983) noted that speakers often interrupt their word errors before completing them, something that should be impossible if the articulation process became ballistic after the onset of a word. Our question, then, is whether speech planning more generally continues beyond the point of response initiation, as opposed to such interruptions representing a special case. Specifically, we contrast ballistic accounts with more dynamic accounts that allow interaction to continue during production. For example, in systems that operate in cascade, later stages of processing can begin before earlier stages are complete (McClelland, 1979; see Dell, 1986, for a seminal application to production). If such cascading allows the articulation of a word to begin before lexical access is complete, then the dynamics of any remaining planning processes may influence articulation independent of the state of the planning system at the moment of response initiation. This can create situations in which measures of planning and articulation effects may diverge.

Among frameworks incorporating interaction, a second key assumption is that the strength of interaction between lexical access and articulation is fixed. For example, exemplar theories have modelled interactive effects by assuming that the lexicon stores detailed phonetic properties; a strict exemplar approach therefore predicts that such

effects should hold constant regardless of whether exemplar retrieval took more or less time (see Fink & Goldrick, 2015, for discussion). Although other theories may emphasize the dynamics of lexical access, they nonetheless assume that the relative timing of planning and articulation remains constant. For example, the minimal planning unit hypothesis (Kawamoto, Kello, Jones, & Bame, 1998) posits that responses are always initiated after some fundamental constituent has been planned (though the underlying planning may take more or less time; see Kawamoto, Liu, & Kello, 2015, for a review).

In contrast to those fixed interactive accounts, another kind of account assumes a temporal coupling of lexical access and articulation can vary. For example, the flexible cascade hypothesis (Kello, MacWhinney, & Plaut, 2000) postulates that the amount of temporal overlap between planning and articulation changes dynamically depending on the speed of processing. The idea, in a nutshell, is that although the neural structure of the production system always has the capacity to support cascading and interactive effects, the emergence of these effects depends on the speed of processing in a given task. Speakers can hasten production by initiating speech based on partial information; so all else being equal, when response initiation occurs earlier, there is predicted to be greater overlap between planning and articulation, yielding more robust lexical effects on articulation (Kello, 2004).

In the current study, we examine the presence of interactivity and its flexibility in the context of *long-distance* interactive effects on articulation, by assessing the conditions under which conceptual and lexical processes may modulate articulatory processing. We begin by discussing the idea of flexible coordination of those planning processes and articulation, reviewing evidence for such long-distance effects, and considering how the

dynamic and flexible nature of interaction might contribute to the mixed findings reported in the literature.

Evidence for the flexible coordination of planning and articulation

Outside of the context of interactive effects, there is evidence that the relative timing of planning and articulation can vary. For example, Kawamoto and colleagues propose that speakers can initiate responding as soon as the first phoneme of a target is phonetically encoded (see Kawamoto et al., 2015, for a review). In support of this claim, results from reading aloud suggest that when the initial phoneme has been primed, response initiation frequently (~1/4 of trials) occurs prior to presentation of the target word. However, in other tasks, response initiation may occur after larger chunks of the target word have been planned (e.g., the syllable or phonological word; Meyer, Roelofs, & Levelt, 2003). Such variable results lead some to argue that phonetic plans are continuously assembled and articulated, rather than being articulated on a unit-by-unit basis (e.g., Pluymaekers, Ernestus, and Baayen, 2005). Critically, these data provide evidence that speakers' response decision criteria may be fairly flexible—consistent with theories claiming that the coupling of lexical access and articulation is not fixed.

Long-distance interactive effects on articulation

Several studies have shown that cascade enables interactions between consecutive stages of production processing, such that disruptions to one stage influence the stage immediately following. For example, the co-activation of a target and its semantic neighbors during lexical selection influences phonological encoding, such that the partial activation of the phonological properties of semantic neighbors biases phonological errors towards semantically related as opposed to unrelated words (e.g., a slip from CAT to RAT is

more likely than a slip from CAT to MAT; for a review, see Goldrick, 2006). Cascade similarly allows partial activation of phonological representations to influence phonetic processing. For example, the partial activation of target phonetic properties causes speech errors to systematically deviate away from an error outcome, towards the intended target (e.g., in a slip from DOG to TOG, the voice onset time of /t/ tends to be more /d/-like than a canonical /t/; for a review, see Goldrick, Keshet, Gustafson, Heller, & Needle, 2016).

Putting these two effects together, we would expect disruptions in lexical selection to cascade into phonological encoding, and then subsequently disrupt articulatory processing. However, the evidence for such long-distance interactions is mixed. Kello et al. (2000) utilized the Stroop paradigm (MacLeod, 1991)—which has been argued to disrupt lexical selection process (Roelofs, 2014)— to test for effects of disrupted lexical selection on word durations. While the authors replicated the finding of semantic interference in RTs—slower responses on incongruent trials (RED written in blue ink) compared to congruent trials (RED written in red ink)—they failed to detect any effect on durations. After changing their task to include a response deadline, though, the interactive effects emerged: when participants suffered impaired lexical selected on incongruent trials, they not only slowed their responses but also increased word durations.

However, in a direct replication, Damian (2003; Experiment 3) failed to detect any effect of Stroop interference on word durations, even under time pressure (see Damian & Freeman, 2008, for similar results in typewritten output). Damian implemented two additional paradigms to rigorously test for long-distance interactive effects. In Experiment 1, Damian used the picture-word interference paradigm (Rosinski, Golinkoff, & Kukish, 1975), where picture naming is slower in the context of semantically related distractor

words than in the context of unrelated words. This has (controversially) been argued to result from disruptions to lexical selection (e.g., Roelofs, 1992; cf. Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). In Experiment 2, participants repeatedly named sets of pictures that were either unrelated or blocked by semantic category. Word production is slower and more error-prone in the semantically blocked condition, which has been argued to result from disruptions to lexical selection by inducing competition from semantically related words (Damian, Vigliocco, & Levelt, 2001) and/or directly reducing the accessibility of previous competitors (Oppenheim, Dell, & Schwartz, 2010). In both tasks, only RTs were modulated by the presence of semantic interference, even under time pressure.

These conflicting duration results suggest that direct interactions between lexical processes and articulation are, if present, weak and difficult to detect. Such subtlety may inherently arise from the architecture of the production system, reflecting restrictions on the strength of interaction and the representational distance between lexical and phonetic representations in the network (see Dell & O'Seaghdha, 1991; Rapp & Goldrick, 2000, for related discussion). Concretely, if co-activation at the lexical level must travel through at least two subsequent levels of representation (phonological and phonetic) in order to impact articulation, each of which is subject to a selection process that reduces the influence of partially activated competitors, then the influence of lexical disruptions may be washed out before it can impact motor execution.

Another possibility (which is not mutually exclusive) is that interactions between lexical access and articulation are not fixed, but can vary. As reviewed above, speakers' response decision criteria may be fairly flexible. Such criteria might vary not only across task conditions (as argued by Kello et al. 2000 and Kello 2004), but also across individual

trials (e.g., post-error slowing; see Notebaert, Houtman, Van Opstal, Gevers, Fias, & Verguts, 2009, for a recent review). If the temporal overlap between planning and articulation is determined by these variable response criteria, then we anticipate variation in interactive effects both within and across studies—which may explain previous difficulties detecting long-distance interactive effects.

A third possibility is that the lack of consistent results reflects between-participant variation in the effectiveness of the experimental manipulations. Recent studies suggest that the degree to which lexical selection is disrupted in tasks such as picture word interference (Shao, Meyer, & Roelofs, 2013) and semantic blocking (Crowther & Martin, 2014; Hughes & Schnur, 2015) is modulated by individual differences in executive functions. This, along with other sources of naturally occurring variation across different samples of participants, may further reduce the likelihood of detecting the already weak effects of long-distance interactions.

Finally, a key issue largely unexamined in previous work is whether long-distance interactive effects arise solely at response initiation (reflecting a ballistic lexical access process) or also arise following response initiation (as predicted by dynamic accounts that allow interaction to continue during production). No studies of long-distance interactions have *directly* examined the extent to which effects in articulatory measures are independent of effects observed during planning. However, Kello (2004) conducted parallel analyses of RTs and word durations in reading aloud, which may provide a useful clue. Orthographic variables (frequency, neighborhood size, and spelling-sound consistency) exerted stronger effects on RTs when there was no pressure to respond quickly. In contrast, the influence of orthographic variables on word duration increased under time

pressure. Although they did not directly test the relationship between these measures, their diverging results suggest that some effects in word duration are not reducible to effects arising during planning.

The current study

The current study aims to clarify the literature on long-distance interactions by addressing the possibility that lexical effects on phonetic variation could arise at multiple time points (at and/or after response initiation), and also examining whether such lexical effects can vary in strength across trials. To that end, we simultaneously consider information about the timing of response initiation and articulation (measured by the acoustic duration of words). In two experiments, we manipulate the semantic properties of the context in which production occurs, utilizing paradigms that are well known to modulate RTs as a function of semantic context.

We then analyze word durations, using multiple regression analyses to examine the extent to which duration effects are reducible to effects on planning (as indexed by by-trial RT and speakers' overall response speeds; for related analytical approaches, see Buz & Jaeger, 2015; Heller & Goldrick, 2014, 2015). If the production system is ballistic, such that all interactive effects are fixed at the moment articulation is initiated, then planning measures and articulatory durations should be positively correlated: as planning time increases, articulatory duration should also increase. Furthermore, there should be no independent effect of semantic context (over and above the effect context has on

planning)[2]. In contrast, if interactive effects arise after the initiation of the response, after controlling for planning effects there will be independent effects of semantic context on durations.

If interactive effects are present, comparison of effects across different trials will allow us to assess the flexibility of such interactions. To the extent that such effects are fixed, any independent effects of semantic context should either appear across all trials in both experiments or in neither. Alternatively, if faster processing yields greater overlap between processes (Kello et al., 2000; Kello, 2004), then interactive effects should increase with faster reaction times.

Finally, as discussed above, participants may vary in their susceptibility to the manipulations of semantic context intended to modulate planning. When planning processes are relatively unaffected by a manipulation, then articulation should be consequently unaffected, preventing the interactive potential of the production system from being detected. Thus, a sample group that includes less susceptible participants may fail to demonstrate direct lexical effects on articulation, even if the potential for such effects is an inherent feature of the structure of the language production system. We therefore consider whether the strengths of direct lexical effects on word durations may be moderated by measures of individual variation.

We utilized two paradigms to modulate lexical and conceptual processing. In Experiment 1, we consider the continuous picture naming paradigm, where speakers

[2] As noted by an anonymous reviewer, this analytic method is conservative; effects occurring after response initiation could have identical effects to independent effects occurring prior to response initiation. Our results are therefore biased against finding any interactive effects after response initiation.

simply named one picture after another in a pseudorandom order (Howard, Nickels, Coltheart, Cole-Virtue, 2006). Crucially, the stimulus list includes exemplars of many different semantic categories, with exemplars of the same category separated by several trials. Many studies have shown that RTs increase linearly with each successive exemplar of a given semantic category, indicating cumulative semantic interference. This interference effect has been argued to arise during lexical selection (e.g., Belke, 2013; Belke & Stielow, 2013; Howard, et al., 2006; Oppenheim, Dell, Schwartz, 2010; but see Navarrete, Mahon, & Caramazza, 2010, for an alternative account). Experiment 2 used the blocked cyclic naming paradigm (Damian et al., 2001), where participants name blocks of pictures that are either blocked by semantic category or mixed; this is the same paradigm in which Damian (2003, Experiment 2) previously failed to detect semantic effects on articulation. Numerous studies have shown that people are slower to name pictures in semantically blocked compared to mixed contexts, indicating cumulative semantic interference during lexical selection (e.g., Breining, Nozari, & Rapp, 2015; Crowther & Martin, 2014; Damian et al., 2001; Schnur, Schwartz, Brecher, & Hodgson, 2006; c.f. Navarrete, Del Prato, & Mahon, 2012, for further discussion).

Experiment 1: Continuous Picture Naming

In our first experiment, participants simply named a sequence of pictured objects one after another, where that sequence has been subtly manipulated to include multiple members of several semantic categories. This continuous picture naming paradigm (Howard et al., 2006) has been shown to reliably induce semantic interference during lexical selection, so we examine whether these effects extend to articulatory processing, as indexed by word durations.

Methods

Participants

We recruited 90 participants at Northwestern University using the Linguistics Department subject pool and flyers around campus. Each received course credit or $10 compensation. They reported learning no language other than English before age 5 and no history of cognitive impairment.

Materials and Design

Participants performed a version of the continuous picture naming task (Howard et al., 2006) administered via SuperLab 4.5, where they named a sequence of pictures as quickly and accurately as possible. Ninety colored line drawings were drawn from Rossion and Pourtois' (2004) database, depicting 5 exemplars from each of 18 semantic categories (average word frequency of 65.3 words per million; SUBTLEX, Brysbaert & New, 2009). Between participants, the stimulus lists were counterbalanced to ensure that each item appeared at every ordinal position within its category (1-5).

Each participant saw stimuli from 9 semantic categories (plus filler trials drawn from non-target categories at the beginning of each test). These were subdivided into 3

blocks, with items drawn from 3 categories in rotation (e.g., a block containing birds, fruits, and vehicles might begin OWL - APPLE - CAR - PEACOCK - ORANGE - PLANE). While dissimilar to the design of Howard et al. (2006), this consistent lag of 2 trials between category members is known to elicit the standard cumulative semantic interference effect (Runnqvist, Strijkers, Alario, & Costa, 2012; Schnur, 2014).

Within trials, we followed Howard et al.'s (2006) design. A fixation cross appeared in the center of the screen for 500 ms, followed by a blank interval of 250 ms. The target appeared onscreen and remained visible for 2000 ms, during which time the participant named the item aloud. The screen then blanked again for an inter-trial interval of 500 ms.

Data processing

The data for experiments 1 and 2 were collected using an AKG C420 headmounted microphone, connected to a MOTU 8Pre digital audio interface. In this and the following experiments, word durations were extracted from stereo recordings. These contained audio markers time-locked to stimulus onsets on the right channel, plus participant speech on the left. After segmenting the recordings into trials using the audio markers, speech onsets and offsets were identified using intensity thresholds. Each trial was first equalized to an average root mean square intensity of 0.02 Pascal. The Praat Intensity function then estimated the intensity contour of the normalized signal. Speech onsets were located by sampling this contour at 1-millisecond (ms) increments to detect when the normalized signal passed a 55 dB threshold. Speech offsets were located in the same fashion, except that sampling began from trial's end. Duration was defined as the difference between speech onset and offset. The first author and a research assistant manually corrected these

boundaries to avoid false triggers due to lip smacks, breathing, and/or low amplitude segments.

Results

Initial filler trials from each block were excluded from analysis. Removing errors (including incorrect responses, non-canonical responses, dysfluencies, and technical errors) eliminated 11.2% of the data. Trials with RTs below 200 ms and above 2000 ms were removed (0.3%), as were those with RTs more than three standard deviations from a given subject's mean (0.5%). RTs were log transformed before analysis to correct for positive skew. Analysis confirmed the presence of cumulative semantic interference in RTs: there was a linear increase in RTs across ordinal positions within each semantic category (see Fink, 2016).

Word durations were log-transformed to compensate for positive skew. Log durations more than 3 standard deviations from a participant's mean were removed, eliminating an additional 0.2% of the data[3]. Analysis of the remaining 3,539 observations is described below.

Model structure

A single mixed-effects regression model was constructed to test for effects of response timing and response selection difficulty on word durations. To examine the coupling of planning and articulation, fixed effects of interest included 1.) by-participant overall speed and 2.) trial-level RT. To examine any independent effects of the semantic manipulation, the model also included 3.) ordinal position within a semantic category (1-

[3] Note that Experiment 2—which does not include hand-correction of response durations—excluded word durations below 100 ms and above 2000 ms. No such word durations were observed in Experiment 1.

5). To account for individual differences in the effectiveness of the semantic manipulation, there was a fixed effect of 4.) by-participant RT interference size. We also examined how these different measures interacted, specifically by including the two-way interactions of 5.) ordinal position by trial-level RT and 6.) ordinal position by RT interference size. Several control variables were also included as fixed effects: 7.) experimental block (1-3), 8.) item class (manmade = -0.5, natural = 0.5), and 9.) a block by ordinal position interaction. All of these predictors were centered to avoid co-linearity. The inter-correlations among fixed effects were low (rs≤0.13), with the exception of by-participant speed and trial-level RT (r=0.43). We therefore report the simple correlations between these predictors and duration to confirm that the direction of their effects is not a spurious result of their high inter-correlation. Following the model selection procedure recommended by Bates, Kliegl, Vasishth, and Baayen (2015)[4], random effects included intercepts for both participants and items; by-participant slopes for ordinal position, block, trial-level RT and class; plus correlation terms.

The by-participant predictors for overall speed and RT interference size were created using simple linear regressions, where participants' continuous naming RTs were predicted by ordinal position only. Specifically, intercepts and beta coefficients were extracted from those RT models and input into the current duration analysis. We note that a more conservative analysis would extract best linear unbiased predictors (BLUPS; Baayen, 2008) from a complete, mixed-effects model of the RT data. Such an approach

[4] This procedure combines principle components analysis and nested model comparisons to avoid problems of overparameterization that typically threaten the convergence and interpretability of models with maximal random effects structures.

estimates the influence of the target predictor, ordinal position, while also taking into account variance from other sources (e.g., block number). However, our participants demonstrated little variance when their ordinal position effects were estimated by this method, rendering the approach unfeasible. (n.b. This provides some initial evidence that individual differences do not make a substantial contribution to this RT effect.)

Relationship between planning measures and duration

Consistent with an influence of the input to articulatory processes on duration, there was a reliable effect of by-participant speed; participants who responded slower overall tended to produce longer word durations (β=0.054, s.e.=0.013, $\chi^2(1)$=14.31, p<0.001; correlation of by-participant speed and duration: *r*=0.18, 95% CI=0.15, 0.22). While the overall effect of trial-level RT patterned in a negative direction, such that faster responses had longer durations, the effect was not reliable (β=-0.018, s.e.=0.016, $\chi^2(1)$=1.24, p=0.27; mean within-participant correlation of trial-RT and duration: *r*=-0.04, s.e.=0.02).

Effects of semantic context

As shown in Figure 1, there was a significant effect of ordinal position on word durations (β=0.005, s.e.=0.002, $\chi^2(1)$=4.33, p<0.05), such that semantic interference slowed the articulation of target picture names. Because this effect remained significant after including planning measures as covariates, we can conclude that it reflects the influence of lexical co-activation on articulation after response initiation.

The two-way interaction of ordinal position and trial-level RT did not significantly affect durations (β=0.002, s.e.=0.007, $\chi^2(1)$=0.07, p=0.80, suggesting that across-trial changes in the temporal overlap between planning and articulation may not modulate these lexical effects on articulation.

Contribution of individual differences

The two-way interaction between ordinal position and the size of RT interference had no reliable effect on word durations (β=0.0003, s.e.=0.001, $\chi^2(1)=0.09$, p=0.77). The size of semantic interference effect in durations was apparently consistent across participants, regardless of whether their RTs indicated large semantic effects prior to response initiation.

Control variables

No other effects approached significance ($\chi^2(1)\leq 2.15$, $p\geq 0.14$). Results for all fixed effects predictors are provided in the Appendix.

Summary

Experiment 1 demonstrated simultaneous effects of response timing and response selection difficulty on articulation during continuous picture naming. In terms of response timing, we found that the global measure of response speed predicted word durations, while the trial-level measure did not. This provides some evidence that articulation reflects the output of planning processes. Critically, over and above these effects, the semantic ordinal position manipulation generated cumulative semantic interference not only in RTs, but also in word durations. This suggests that lexical co-activation can continue to influence articulation after response initiation. Given the absence of interactions between trial-level RT and semantic context in predicting word durations, these results do not provide strong support for the claim that the temporal overlap between processes increases with faster processing speed. Finally, there was no evidence that individual differences in the effectiveness of the semantic manipulation modulated these effects,

though, as noted above, our ability to detect such variation in articulatory effect was limited by the homogeneity in the strength of our participants' RT effects.

Experiment 2: Blocked Cyclic Picture Naming

Our second experiment utilized the blocked-cyclic naming paradigm (Belke et al., 2005) to investigate the relationship between lexical access and articulation. Because this block-wise design is more conspicuous than the continuous one (Experiment 1), participants may be able to engage top-down control to resist the accumulation of semantic interference (Belke & Stielow, 2013). Within any block, participants repeatedly name a limited set of items across several cycles, and this constrained response set may allow more strategic preparations, such as active inhibition of non-target responses. As a result, Experiment 2 allows us to examine the coordination of planning and articulatory processes under conditions subject not only to semantic interference, but also to control processes intended to moderate that interference.

Methods

Participants

96 undergraduate students were recruited from the Psychology Department subject pool at the University of California San Diego. All reported to be native speakers of English, with no history of language or psychological disorder, and normal or corrected-to-normal vision and hearing. 2 participants were excluded from the analyses below due to a technical error in their response recordings.

Materials and Procedure

Similar to Experiment 1, the data reported here were originally collected for a separate study of cumulative semantic interference effects on RTs (Oppenheim, in prep).

The PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) experiment began with a familiarization phase, where participants named a series of 96 line drawings, including 72 critical items (6 members each of 12 categories; from Schnur et al, 2006) and 24 fillers representing four additional semantic categories (from Szekely et al, 2003). Items were pseudorandomly organized into four blocks of 24 trials, each followed by a self-paced break. On each trial, after the voicekey triggered or 3000ms had passed, the picture's desired name appeared below it for 750ms; participants were instructed to use this name in the remainder of the experiment.

In the test phase of the experiment, participants encountered the same 96 line drawings, this time organized into mixed vs. semantically homogeneous blocks. Mixed blocks were composed of 6 items belonging to 6 different semantic categories (e.g., *dog*, *arm, stapler*); homogeneous blocks contained 6 items from a single semantic category (e.g., *dog*, *goat, horse*). Each block began with a filler item, followed by six critical items that were repeated in different orders across four cycles (24 test trials per block). Each trial ended when the voicekey was triggered, or after 2000ms if no response had been detected. Self-paced breaks were offered between blocks.

The test phase was divided into two halves, each containing 6 homogeneous and 6 mixed blocks. Though it is beyond the scope of this article, these blocks were arranged in two formats: half of the participants saw the block types clustered, the other half saw them interleaved.

Data Pre-Processing

RTs were collected online using a Shure SM10a headmounted microphone, connected to an ioLab response box, implementing a delayed-threshold voice-key. Word

durations were automatically extracted from the Marantz PMD 661 stereo recordings using the procedure outlined in Experiment 1, except that boundaries were not hand-corrected due to the large scale of the data set (over fifty thousand observations). It is likely that the large number of observations will reduce the impact of boundary-marking errors. Additionally, any errors that occur will be blind to condition, and so should not introduce any systematic bias in our analyses.

Results

An initial data cleaning process removed fillers, incorrect responses, and recording errors (6.0%). From there, RTs below 200 ms and above 2000 ms were removed (0.1%), as were RTs more than 3 standard deviations from the participant mean (1.3%). We then excluded durations below 100 milliseconds and above 2000 milliseconds (0.1%) and log transformed the data to compensate for positive skew. Outlier trimming removed data points more than 3 standard deviations from each subject's mean log duration, eliminating an additional 0.6% of trials, thus leaving 50,839 observations for this analysis.

Model structure

Fixed effects of interest included 1.) by-participant overall speed, 2.) log trial-level RT, 3.) semantic context (blocked=-0.5 vs. mixed=0.5), 4.) by-participant RT interference size, and the two-way interactions of 5.) semantic context by trial-level RT and 6.) semantic context by RT interference. If semantic interference affects articulation in this task, then we should expect longer durations in semantically homogeneous blocks compared to mixed blocks. Additional fixed effects were added as control variables: 7.) experiment format (clustered block types= -0.5 vs. interleaved block types=0.5), 8.) block within the experiment (1-12), 9.) cycle within the block (1-4), 10.) the number of trials since the

picture was last named (repetition lag, 1-9), and 11.) whether an item had been named in a previous block. The two-way interactions of semantic context with 12.) block, 13.) cycle, and 14.) repetition lag were also allowed. Inter-correlations among the fixed effects were relatively low (*r*s≤0.22); however, to maintain parallelism with the first experiment, we report simple correlations for overall speed and trial-level reaction time. Random effects included intercepts for 15.) participants and 16.) items; by-participant slopes for 17.) semantic context, 18.) whether an item was previously named, 19.) cycle, 20.) block, 21.) trial-level RT, and the two-way interactions of 22.) context by previous naming and 23.) context by block; and by-item slopes for 24.) experimental format, 25.) overall speed, 26.) context, 27.) trial-level RT, 28.) the size of RT interference, and the two way interactions of 29.) context by previous naming, 30.) context by block, and 31.) context by trial-level RT.

Unlike in Experiment 1, the current by-participant predictors were generated using BLUPs from the full mixed effects model of participants' RT data, rather than beta coefficients from simple regressions. The RT model had the same fixed effects structure as the duration model, except for the absence of any by-participant predictors. Its random effect structure was determined using the same model selection procedure as in Experiment 1 (Bates et al., 2015); it included intercepts for participants and items, plus by-participant and by-item slopes for all fixed effects. As noted above, BLUPs from mixed effects models surpass other regression techniques because each individual estimate is made in light of the entire data set; the random effects are assumed to reflect samples from a larger population (Baayen, 2008). This approach was possible in the current experiment because there was more variation across participants in the target semantic effect on RTs.

This provides some initial support for a substantial contribution of individual differences to performance in this task.

Relationship between planning measures and duration

Consistent with Experiment 1, we observed an effect of by-participant speed, such that generally faster responders produced shorter durations (β=0.50, s.e.=0.024, χ^2=4.31, p<0.05; correlation of speed and duration: *r*=0.14, 95% CI=0.13, 0.14). In contrast to the non-significant trend in Experiment 1, trial-level RTs echoed this positive relationship, such that faster responses also tended to exhibit shorter word durations (β=0.054, s.e.=0.014, χ^2=14.44, p<0.001; mean within-participant correlation of trial-RT and duration: *r*=0.10, s.e.=0.009). Both results are consistent with an influence of the input to articulatory processes on duration.

Effects of semantic context

In contrast to Experiment 1, we found no overall effect of semantic context on word durations (β=-0.0001, s.e.=0.003, χ^2<0.01, p=0.99). Regardless of whether pictures were blocked by semantic category or intermixed, durations did not vary. Semantic context had no reliable interaction with trial-level RT or any of the control variables (χ^2≤2.36, p≥0.12).

Contribution of individual differences

Critically, the magnitude of effects of semantic context on participants' naming latencies modulated the effect of semantic context on their word durations (β=0.005, s.e.=0.002, χ^2=9.93, p<0.01). As shown in Figure 2, participants who were more susceptible to the context manipulation, as indexed by the size of their RT interference effects, were more likely to show similar interference during articulation. In other words, if lexical co-

activation was especially intense during planning, it was more likely to continue affecting processing after response initiation.

Control variables

Two control variables influenced word durations. Consistent with previous work (e.g., Bell et al., 2009), an effect of repetition lag indicated the presence of repetition priming—naming *cat* reduced the duration of subsequent namings of that *cat*—which dissipated over intervening trials (β=0.0013, s.e.=0.0004, $\chi^2(1)=11.79$, $p<0.001$). There was also a marginal effect of experimental format, such that word durations were longer when semantic blocks (mixed vs. homogeneous) alternated as opposed to being grouped together. No other effects reached significance ($\chi^2 \leq 1.02$, $p \geq 0.31$). Results for all fixed effects predictors are provided in the Appendix.

Summary

Experiment 2 exhibited the consistent coupling of planning and articulation predicted by the planning-drives-articulation hypothesis. As in Experiment 1, we found an independent effect of semantic interference on word durations; however, there were also important differences. There was no overall effect of semantic context on articulation in Experiment 2. This contrastive result may reflect engagement of top-down cognitive control in the current blocked naming task (Belke & Stielow, 2013; see also Oppenheim et al., 2010: 237-238 for similar discussion), which could have dampened the activation of semantically related items, thereby preventing them from influencing processing after response initiation.

Importantly, an interaction between semantic context and our estimates of participants' overall RT interference size revealed that a subset of participants—those

whose RTs revealed greater susceptibility to semantic manipulations—*did* exhibit interference in their durations. (This may, in fact, be another consequence of the engagement of top-down control; such strategic processes may exhibit more between-participant variability than the automatic control processes engaged in Experiment 1.) Our ability to detect this interaction for word durations in Experiment 2 most likely stems from the presence of greater variability in its RT context effect. Consistent with greater variability across participants, the RT model for Experiment 2 retained the random by-participant slope for semantic context, indicating significant variation in the effect size; in contrast, the by-participant slope for ordinal position was algorithmically dropped from the RT model for Experiment 1 during stepwise model reduction (Fink, 2016). In general, the interaction between semantic context and RT interference size demonstrates how consideration of individual variation can enhance our ability to detect long-distance interactive effects.

General Discussion

To account for articulatory consequences of factors influencing lexical access, theories of production propose that there is interaction between lexical access and articulatory process. But, perhaps as an artifact of the historical division between cognitive and motor research, even interactive theories tend to assume a fixed separation between planning and articulation modules. In the current work, we examined two implicit assumptions of many interactive theories. First, we explored whether the relationship between lexical access and articulatory processing is ballistic, or whether ongoing planning continues to influence articulation after a response has been initiated. Two experiments revealed that semantic interference effects affected phonetic variation after response

initiation. After taking into account effects at response initiation (reflected by RTs), we observed significant effects of semantic context on word durations, supporting the presence of long-distance interactions between lexical selection and articulatory processing. Detection of these effects in the blocked-cyclic naming paradigm was made possible by taking into account variation in semantic interference effects across participants. (Note that an important question is whether such variation ultimately represents *stable* differences between individuals, or simply reflects situation-specific variation in performance.)

Second, we examined the degree to which the link between planning and articulation is fixed, as many interactive theories assume, or if this link can vary. We found no evidence that, within a task, faster RTs (predicted to yield greater overlap between planning and articulation) increased interactive effects. This suggests that interactive effects arising during lexical selection may be relatively fixed features of the architecture of each speaker's production system. However, it is possible that participants did not naturally vary their response speeds to the extent needed to yield shifts in interactive effects (recall that Kello et al. (2000) externally manipulated response initiation time). If Kello et al.'s (2000) finding of greater interactivity with extreme response time compression can be replicated (a serious concern given the results of Damian, 2003), future studies using this paradigm should examine more closely the conditions under which such shifts can occur.

It is important to note that several effects varied across the two experimental tasks[5]. In Experiment 2, faster trial-level RTs were coupled with shorter word durations, but a non-significant trend in the opposite direction was observed in Experiment 1. This difference likely reflects the use of a fixed trial duration in Experiment 1: with a fixed trial duration, initiating a response later allowed less time for its completion. Second, when participants named pictures just once in a pseudorandom order, we found an overall effect of semantic interference on word durations (Experiment 1), but when participants named pictures repeatedly in a semantically blocked structure, no such effect emerged until we factored in individual variation in the magnitude of the semantic interference that we elicited at the lexical level (Experiment 2). This differential modulation suggests that subtle downstream effects of lexical disruptions on articulation may only be detected when those upstream disruptions are fairly robust to begin with, and may thereby explain some discrepancies among previously published results.

More generally, the variable influence of different measures of response timing, along with variation in interactive effects across tasks and individuals, suggests that considering articulation and lexical access in isolation is likely to continue to yield inconsistent, inconclusive findings. Interactive theories need to more carefully consider the dynamic nature of the production system and its interactions with the broader cognitive system (see Fink & Goldrick, 2015, for additional discussion).

Implications for theories based on communicative goals

An alternative approach to understanding lexical effects on phonetic variation—complementing interactive theories' focus on mechanisms—comes from theories that

[5] See Fink (2016) for discussion of contrasting results in a semantic classification task.

emphasize the importance of communicative goals in shaping pronunciation variation (e.g., Aylett & Turk, 2004; Buz, Tanenhaus, & Jaeger, 2016; Lindblom, 1990; Scarborough, 2004; Scarborough & Zellou, 2013; Wright, 2004; see also Balota, Boland, & Shields, 1989, for discussion). For example, speakers tend to hyperarticulate words in unpredictable contexts, while reducing predictable words. This can be seen as reflecting a process that maximizes articulatory effort in contexts where the probability of successful communication is reduced.

Some of the effects observed in the current experimental tasks could be attributed to communicative factors. The lengthening of words when retrieval is difficult (during cumulative semantic interference, or for speakers that have great difficulty with semantic blocking) could be analogous to the lengthening of determiners (saying *the* as "thiy" vs. "thuh") to signal retrieval difficulties to listeners (Fox Tree & Clark, 1997). This could provide a functional motivation for the direct effects of lexical access variables on phonetic variation we observe here. However, the independent and sometimes contrasting effects of various response timing measures on articulation suggest a need to articulate how such communicative factors interact with other constraints on speech production.

Conclusions

Many interactive accounts have implicitly assumed that all articulatory variation is generated by processing prior to response initiation, with a fixed relationship between planning and articulatory processes. Our results suggest that lexical effects on articulatory outcomes can arise from multiple sources, both before and after a response has been initiated. Additional research simultaneously analyzing planning and articulatory measures is needed to help constrain the complex empirical landscape of interactive effects.

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Figure Captions

Figure 1. Mirroring the classic RT effect (e.g. Howard et al., 2006), mean word durations (ms; error bars show standard errors) for continuous picture naming in Experiment 1 increase as a function of a words ordinal position within its semantic category.

Figure 2. Best unbiased linear predictors (BLUPs) of RT interference size (x-axis), extracted from mixed effects model of RT data. These reliably predicted the presence of semantic interference in durations (ms; y-axis). Dotted line shows linear regression fit (standard error of regression shown in grey).

Figure 1

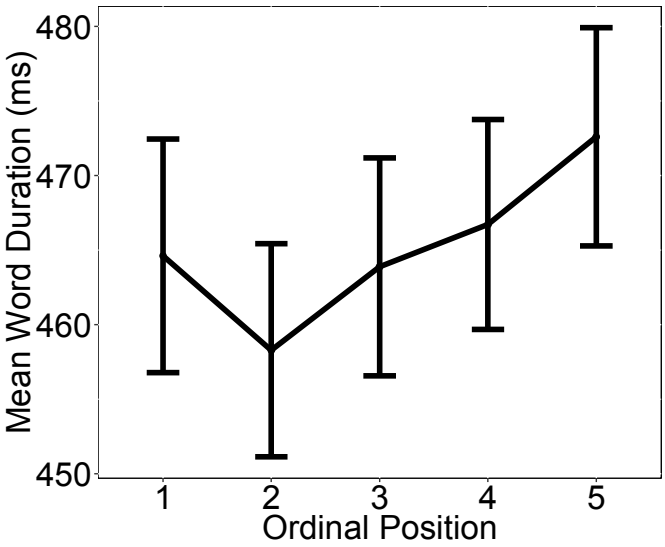
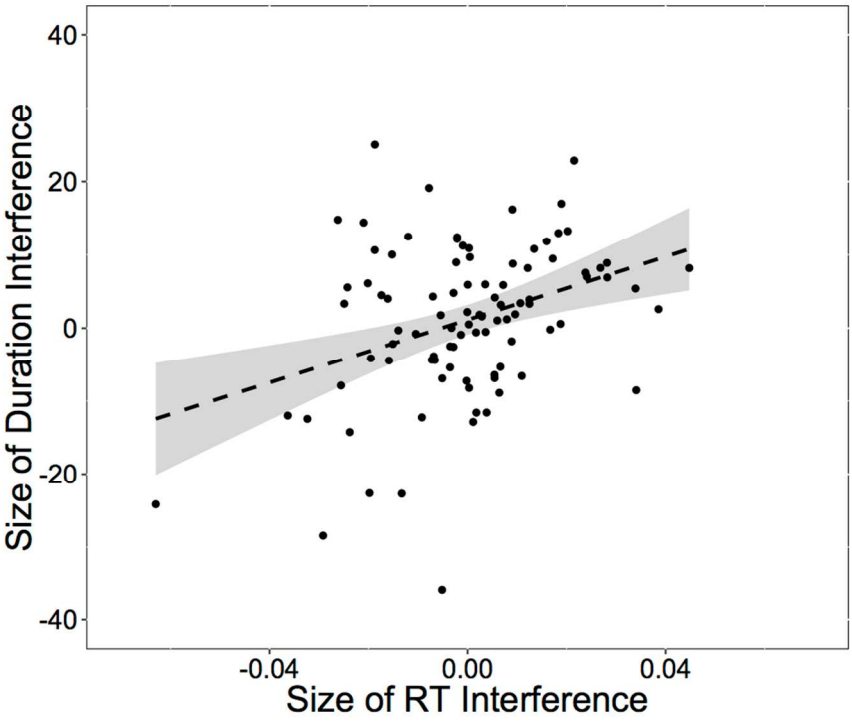

480
470
460
450
Mean Word Duration (ms)
1
2
3
4
5
Ordinal Position

Figure 2


40
20
0
-20
-40
Size of Duration Interference
-0.04
0.00
0.04
Size of RT Interference

Appendix

Table A1. Results for full set of fixed effects predictors, Experiment 1

Predictor	Beta	S.E.	Chi-sq	P-value
Ordinal Position	0.005	0.002	4.33	0.04*
RT Interference	-0.003	0.006	0.24	0.63
Trial-level RT	-0.018	0.016	1.24	0.27
Speed	0.054	0.013	14.31	<0.001***
Class	0.044	0.038	1.31	0.25
Block	0.010	0.007	2.15	0.14
Ordinal Position x RT Interference	0.0003	0.001	0.09	0.77
Ordinal Position x Trial-level RT	0.002	0.007	0.07	0.80
Ordinal Position x Block	0.005	0.003	2.15	0.14

. marginally significant at the level of 0.05 < alpha < 0.10
* significant at the level of alpha = 0.05
** significant at the level of alpha = 0.01
*** significant at the level of alpha = 0.001

Table A2. Results for full set of fixed effects predictors, Experiment 2

Predictor	Beta	S.E.	Chi-sq	P-value
Semantic Context	-0.0001	0.003	<0.01	0.99
RT Interference	-0.007	0.011	0.40	0.52
Trial-level RT	0.054	0.014	14.44	<0.001***
Speed	0.050	0.024	4.31	0.04*
Repetition Lag	0.001	0.0004	11.54	<0.001***
Block	-0.002	0.002	1.02	0.31
Cycle	0.0002	0.001	0.02	0.89
Named in Previous Block	-0.0003	0.001	0.52	0.46
Experimental Format	0.071	0.037	3.61	0.06.
Semantic Context x RT Interference	0.005	0.002	9.93	0.002**
Semantic Context x Trial-level RT	0.018	0.012	2.36	0.12
Semantic Context x Block	-0.0006	0.003	0.04	0.85
Semantic Context x Cycle	-0.002	0.002	1.22	0.27
Semantic Context x Previous Naming	-0.009	0.012	0.56	0.46

. marginally significant at the level of 0.05 < alpha < 0.10
* significant at the level of alpha = 0.05
** significant at the level of alpha = 0.01
*** significant at the level of alpha = 0.001