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Processing linguistic variation through dual mechanisms of cognitive control

Abstract: While rarely difficult for the average speaker/listener, the ubiquity of variation at all levels of linguistic production is a challenge for modern psycholinguistic models of language processing. Variation is perhaps most extreme at the levels of phonetics and phonology, but many models of language processing all but eschew these levels altogether. The current paper posits that cognitive control mechanisms, when divided into proactive and reactive control via a dual mechanisms framework may effectively describe the strategies individuals use to process linguistic variation and, when incorporated into language processing models, can generate novel, testable predictions regarding the origin and propagation of individual differences. By means of example, I illustrate how dual mechanisms of control could be incorporated into a connectionist model of language production. I then describe how dual mechanisms of cognitive control might be relevant for the Adaptive Control Hypothesis and how individual differences in processing strategies may modulate participation in language changes-in-progress.

Keywords: cognitive control, language processing, individual differences, PsychLingVar, language variation and change

1 Introduction

1.1 The ‘problem’ of linguistic variation

Variation is an inherent property of language (e.g., Weinreich et al. 1968). The average speaker/hearer contends with variation in syntactic structures (e.g., active vs. passive, double object vs. prepositional object), lexical item (e.g., synonyms, regionalisms), and phonological inventory (e.g., conversation between an individual with the pen/pin merger and one without), yet rarely does communication suffer. Even at the level of phonetics, which is perhaps the most variable of all, individuals with no linguistic training demonstrate an astounding capacity to account for acoustic variation. Listeners can adapt to physiological differences, coarticulation/gestural overlap, multiple speakers, and noisy speech, among other factors. What is more, exposure to variable patterns may ultimately result in more flexible mental representations and improved ability to adapt to novel input (e.g., Clopper 2014); in this sense, exposure to variation is more of an advantage than a problem. Current models of language processing are limited in their treatment of variation, but recent findings from research on monolingual and bilingual populations alike indicate that variation can no longer be neglected in an ecologically-valid model of language processing.
1.2 Accounting for variation in psycholinguistic models of language processing

Most psycholinguistic models of language processing are centered on the lexeme and only consider phonetics and phonology in passing (e.g., Dijkstra and van Heuven 2002; Bock and Levelt 1994; Green 1998). These lexicalist models cannot easily account for a number of phenomena arising from variation: frequency effects in reduction (e.g., Gahl 2008; Brown and Raymond 2012; Ernestus et al. 2006; Gahl et al. 2012), perceptual compensation for coarticulation or speaker idiosyncrasies (e.g., Kraljic et al. 2008; Yu 2010; Magnuson and Nusbaum 2007), and lexical retuning (e.g., Jesse and McQueen 2011; Davis et al. 2005), to name a few (see also Fink and Goldrick 2015). Although some of these models, such as interactive connectionist models (e.g., Dell 1985, 1986; Dell and Gordon 2003), account for phonological neighborhood density and phonetic reduction, they do not easily incorporate variation due to segmental/gestural overlap, nor do they make strong predictions regarding the emergence, propagation, and range of variation that inevitably arise within and across speakers both as individuals and as members of a speech community.

Exemplar models (e.g., Pierrehumbert 2001; Goldinger 1998; Wedel 2007), in contrast, excel in their treatment of variation. These models, which primarily emerge from laboratory phonology, posit that highly detailed information about an utterance, the individual speaking, and the context in which an utterance is used are stored mentally and can influence future language processing. This approach allows exemplar models to account for many of the aforementioned phenomena and describe individual differences in language processing. The primary limitations of this class of models, however, is that they do not typically specify the cognitive mechanisms by which exemplars are stored, accessed, or activated, nor do they indicate how processing at one level may influence processing at another (see Fink and Goldrick 2015).

Most individuals actually experience language through phonetics (i.e., through spoken conversation). Ergo, any ecologically-valid psycholinguistic model must account for phonetic variation, its relation to other levels of processing, and the cognitive mechanisms that allow individuals to navigate variation in their environment. I argue that intra- and inter-speaker variation can be explained in psycholinguistic models using pre-existing concepts deriving from domain-general cognitive mechanisms. Namely, I claim that proactive and reactive control mechanisms (e.g., Braver et al. 2007; Braver 2012) can describe individual differences in processing variation in phonetics and beyond, and that a model incorporating these mechanisms makes novel predictions regarding how continued engagement of distinct processing strategies can effect individual differences in language use and structure more generally.

2 Cognitive control in language processing

Cognitive control is a hypernym referring to the mechanisms individuals use for monitoring, attending to local context, inhibition, storing information in memory, and other so-called executive functions (e.g., Dreisbach 2012; Braver 2012). They represent the processes an individual may engage, either voluntarily or involuntarily, in order to attend to a given stimulus or situational context. Cognitive control is thought to be fluid and dynamically adaptive (see Cole et al. 2013), but cognitive control also varies within and across individuals (e.g., Botvinick et al., 2001) as a consequence of factors such as innate ability, experience, or attention to task demands (cf. Mattys and Wiget 2011; Theodore et al. 2015; Mattys and Palmer 2015).

2.1 Conflict monitoring and cognitive control

Most research on cognitive control in language processing has been conducted under a conflict monitoring framework (e.g., Botvinick et al. 2001). This approach postulates that in situations where two processes or stimuli conflict (or are likely to do so), cognitive control is employed in order to resolve competition. Cognitive control is hypothesized to adjust to task demands, making the amount of control required vary
according to the experimental context. For example, *ceteris paribus*, inhibition effects are greater when conflicting information occurs infrequently than when it occurs frequently (e.g., Lindsay and Jacoby 1994; Gratton et al. 1992). This suggests that more control is required to overcome less predictable conflict.

With regard to language processing, cognitive control has been implicated in ambiguity resolution for syntax (Novick et al. 2005; Novick et al. 2014; Vuong and Martin 2014; Hsu and Novick 2016; Teubner-Rhodes et al. 2016), lexicon (Vuong and Martin 2011; Khanna and Boland 2010), and phonetics and phonology (Lev-Ari and Peperkamp 2013, 2014; Darcy et al. Forthcoming). Cognitive control has also been implicated globally, either to suppress perspectives (Brown-Schmidt 2009; Nilsen and Graham 2009) or entire languages (Kroll and Bialystok 2013; Green and Abutalebi 2013). In general, greater cognitive control correlates to improved conflict resolution (see Ye and Zhou 2009 for a review).

This finding is also reflected in language learning research. Khanna and Boland (2010) investigate the implications of cognitive control on 7–10 year olds’ ability to resolve lexical ambiguity (e.g., ‘tag’ as the game vs. a label on a shirt collar) relative to adults. The researchers found evidence that more mature executive functions (working memory and inhibition) were associated with more adult-like patterns of behavior in children, supporting a contextual developmental account where context usage is facilitated by cognitive control (see also Woodard et al. 2016 for supporting evidence in 5–6 year olds with syntax). Darcy et al. (Forthcoming) test the importance of cognitive control in adult language learning, investigating how inhibitory control correlates to acquisition of second language phonology. Using production and perception tasks with English-Spanish bilinguals, the researchers find that individuals with higher inhibitory control had lower incidences of errors in segmental perception and better pronunciation accuracy for phonological contrasts involving L2-specific consonants (Spanish: /ɾ/-d/; English: /ʃ/-tʃ/).

Under a strict conflict monitoring framework (e.g., Botvinick et al. 2001), cognitive control is a singular construct: conflict is presented or expected, and control is directed to resolve it. For example, performance on the Stroop task (e.g., Stroop 1935), where individuals read color words in ink that is either the same or different color as the word (e.g., *GREEN* in green text vs. *GREEN* in red text), is used to evaluate one’s ability to process conflict. However, recent research suggests that two qualitatively different types of cognitive control may be at play in this task: one a top-down process of context monitoring, and the other a process of reaction that is stimulus-driven (e.g., Bugg 2012; Gonthier et al. Forthcoming). A framework which treats cognitive control as an interrelationship among related mechanisms rather than along a single dimension may be more flexible and better account for individual and community variation. Additionally, it generates subtler predictions regarding conflict resolution while still remaining compatible with a conflict monitoring framework.

### 2.2 Dual mechanisms of cognitive control

A recent approach by Braver and colleagues interprets cognitive control as the interrelationship between two semi-independent operating modes (cf. Braver and Barch 2002; Braver et al. 2007; Braver 2012). The first, called proactive control, refers to the ability to hold a cue in memory (also called context/cue maintenance or monitoring). The second, reactive control, refers to the mechanisms used to respond after encountering a stimulus. Importantly, while the two control strategies may provide similar benefits, they may confer distinct processing costs (Gonthier et al. Forthcoming). The two mechanisms are thought to be in some respect complementary, and any given individual will use a combination of both strategies when processing information online (e.g., Braver 2012: 107). Individuals vary in their relative use of these mechanisms, either due to cognitive differences (e.g., fluid intelligence; see Burgess and Braver 2010) or differences in affective traits (e.g., reward or threat sensitivity; see Braver 2012), but most develop a preference for one type of control over the other. Thus, two individuals with the same usage of one strategy as opposed to the other may differ in the absolute strength of these mechanisms.

Proactive control mechanisms are analogous to top-down processing strategies in that they bias processing while active (e.g., avoiding tempting distractions throughout the day because manuscript
revisions are due that evening). As such, proactive control strategies are thought to be cognitively costly (e.g., Braver et al. 2007). However, in situations where conflict is predictable (e.g., when incongruent Stroop trials are presented frequently; cf. Braver et al. 2007; Bugg 2012; Gonthier et al. Forthcoming), the costs may be outweighed by performance benefits. In contrast, reactive control is a bottom-up process engaged by the stimulus, requiring reactivation of task goals to resolve conflict (e.g., accepting an invitation, seeing the manuscript while leaving the house, and then canceling). Developmental evidence suggests reactive strategies are earlier to develop than proactive strategies (Chatham et al. 2009; Khanna and Boland 2010; Woodard et al. 2016), and an inverse correlation between fluid intelligence and reactive control has been observed (Burgess and Braver 2010). Reactive control is also thought to be metabolically less costly than proactive control. However, a disadvantage of using reactive control is that one can be disrupted by distractors in the surrounding context, and these mechanisms depend on salient cues to reactivate task goals (here, the manuscript; cf. Braver et al. 2007; Braver 2012).

Studies explicitly investigating proactive and reactive control have hitherto been relegated to areas unrelated to language processing, and nearly always as the basis of comparison of one population to another. For example, these control mechanisms have been used in research on language development to show age-related increases in executive function (e.g., Lorsbach and Reimer 2008), on cognitive aging to demonstrate age-related decline in these functions (cf. Haarmann et al. 2005; Rush et al. 2006), and in clinical psychology to describe differences between ‘neurotypical’ and pathological populations (e.g., individuals with autism spectrum disorder, Bodner et al. 2012; sufferers of traumatic brain injury, Larson et al. 2006). Only recently have proactive and reactive control been utilized in psycholinguistic work, but again to compare populations rather than analyze language processing per se. In the rapidly growing bilingualism literature, proactive and reactive control have been used to compare processing efficiency in bilinguals as opposed to monolinguals. For example, Morales et al. (2013) find behavioral evidence that bilinguals better utilize both of these control mechanisms than their monolingual peers. In a follow-up study utilizing event-related potentials (ERPs), Morales et al. (2015) replicate behavioral findings and find additional support in the ERP record: bilinguals more flexibly use both control mechanisms, while monolinguals tend to favor one strategy over another.

One of the few studies to explicitly link language processing to a dual mechanisms framework is work by Columbus et al. (2015). The researchers used eye-tracking methods to investigate the interrelationship of reactive control and predictability in metaphor/idiom resolution, but did not include measures of proactive control in their analysis. Results indicated that more reactive control was used when the preceding context required metaphorical interpretation of the stimulus (Columbus et al. 2015: 4–6). Presumably, proactive control strategies would have led to greater accuracy and reaction time when the preceding context cued a metaphor, since proactive strategies rely on top-down strategies engendered by context that influence subsequent processing.

Lexical competition (e.g., synonyms, cognates for bilinguals) and competition among syntactic structures (e.g., verb bias or garden paths) could be interpreted through the lens of proactive and reactive control. As Columbus et al. (2015) found, individuals who have strong reactive control strategies may show higher reading times for words when the previous context suggests a metaphorical interpretation; this should hold true for synonyms and interlingual homographs as well. Such a result would also be expected at the syntactic level, since similar strategies may be involved. Explicitly, reactive control is hypothesized to correlate to more errors or longer reading times on less frequent interpretations of garden paths and less preferred subcategorization biases. In contrast, individuals with stronger proactive control mechanisms are expected to use more top-down strategies in processing, and thus may be less susceptible to lexical and syntactic conflict. In the case of Columbus et al.’s (2015) study, participants with stronger proactive control may have developed a strategy of holding both metaphorical and literal interpretations in memory. The cognitive load associated with co-activating multiple senses of the target verb would be outweighed by facilitation in processing ambiguous sentences, provided those resources are available. This may be more difficult at the syntactic than the lexical level, since both lexemes and their hierarchical relationships must be held in memory.
Language is an immensely complicated confluence of prediction, reaction, and competition, and the fact that language is encountered so often and occurs with so little disfluency is a testament to individuals’ capacity to use cognitive mechanisms to navigate their linguistic input and output effectively. Moreover, discourse depends on continual interaction of bottom-up and top-down processes that echo the cognitive control strategies in the dual mechanisms framework. As such, it is striking that little research has integrated proactive and reactive control with language processing. The remainder of this paper will illustrate how proactive and reactive control can be measured and correlated to processing linguistic variation and how the inclusion of these strategies in psycholinguistic models improves the predictive capacity, as well as the implications of these strategies for the propagation of inter- and intra- individual differences over time.

3 Measuring proactive and reactive control

Cognitive control has been quantified using a series of tasks, each of which measures a single dimension of executive function. For example, the Stroop task (Stroop 1935), Simon task (Simon 1969), and Eriksen Flanker task (Eriksen and Eriksen 1974) measure one’s ability to attend to relevant information and inhibit irrelevant information. However, latent variable analyses have revealed strong interdependence among functions traditionally held to be distinct (e.g., Prepotent Response Inhibition and Resistance to Distractor Interference; Friedman and Miyake 2004) and a surprising lack of correlation in tasks believed to tap into similar cognitive mechanisms (cf. Friedman and Miyake 2004; Christopher et al. 2012). These findings speak to the advantages of a more parsimonious approach to executive function. Nonetheless, comparison among multiple measures of postulated mechanisms (in this case, proactive and reactive control) is valuable to ensure that the measures adequately represent the mechanisms of interest.

3.1 Adapting standard executive control tasks to measure dual mechanisms of control

Common cognitive control tasks can be adapted to measure proactive and reactive control. For example, Gonthier et al. (Forthcoming) modified a picture-word interference version of the Stroop task at both list and item levels. To promote a proactive strategy, researchers created an experimental block with lists containing 25%, 50%, or 75% congruent items. To promote a reactive strategy, they also developed a block in which certain items occurred more frequently in congruent rather than incongruent conditions (e.g., cat superimposed on a drawing of a cat). Gonthier et al. distinguish a “congruency cost” (slowing on congruent trials in the lists with mostly incongruent items relative to the lists with mostly congruent items), which is representative of proactive control, from a “transfer cost” (lack of processing benefit for unbiased items relative to biased items in item-specific lists), which is representative of reactive control. The researchers find evidence for these two costs, providing support for the existence of two control strategies and offering researchers a straightforward operationalization of individual differences in these mechanisms.

Another alternative is the n-back task with “lures” (e.g., Kane et al. 2007; Novick et al. 2014: 191). In the standard n-back task, participants see a series of letters and are required to indicate if a target stimulus also occurred n letters ago. “Lures” are added to some trials by including copies of the target stimulus at either the n−1 or n+1 position. A proactive strategy will draw attention from distractors between the target and the n-back stimulus. Reactive control is required to resist the temptation to respond yes to the lure, when present. No current study has explicitly measured proactive vs. reactive control on the lures version of the n-back task (though see Gray et al. 2003; Burgess and Braver 2010), but proactive control could be

1 See Gonthier et al. (Forthcoming: 4) for a visual representation of these predictions.
approximated by the sensitivity index on n-back trials with no lures, and reactive control could be operationalized by measuring sensitivity on n-back trials with lures.

### 3.2 The AX-CPT paradigm

The most common task to measure dual mechanisms of cognitive control is AX-CPT, which is a variant of continuous performance tasks used in schizophrenia research (Servan-Schreiber et al. 1996; Cohen et al. 1999, *inter alia*), because both proactive and reactive control must be utilized in order to respond to the task demands (e.g., Braver and Barch 2002; Braver et al. 2007; see also Botvinick et al. 2001: 635). The AX-CPT task consists of blocks of five letters presented individually, and participants must press one of two keys (labeled “yes” and “no”) depending on the stimulus. Participants press “no” in all cases except one: when the probe (the second red letter) is an X and the previous cue (the first red letter) was an A, participants must press “yes” for the X probe (see Figure 1). Importantly, trials are weighted to favor this scenario: 70% are “AX” trials. The trials of interest are “AY” trials (10%), where the cue is A but is followed by a probe other than X, and “BX” trials (10%), where the cue is not A but the probe is X (the final 10% are filler “BY” trials, where neither prompts a “yes” response). Individuals are expected to perform poorly on the AY trials relative to other trials due to the biasing nature of the AX trials (e.g., Braver and Barch 2002: 812).

![Figure 1: Schematization of an AX trial block in the AX-CPT paradigm.](image)

To measure proactive and reactive control, either accuracy (Morales et al. 2015) or reaction times (cf. Braver and Barch 2002; Columbus et al. 2015) have been used. Errors on AY trials are indicative of errors due to proactive control, since the A combined with the frequency of AX trials biases a “yes” response. In contrast, errors on BX trials are indicative of errors due to reactive control, since the frequency of AX trials biases an “X equals yes” strategy (cf. Morales et al. 2015: 158–159). With respect to reaction times, higher response latencies to AY trials relative to AX trials indicate stronger proactive control, since the participant is more strongly attached to the bias engendered by the abundance of AX trials. Similarly, higher response latencies to BX trials relative to BY trials reflect a failure to effectively react to the X probe and shut down the “X equals yes” approach.

### 4 Incorporating dual mechanisms of control into models of language processing

Proactive and reactive control, which are based on domain-general mechanisms and well-studied in research related to language processing, can be included in psycholinguistic models. Doing so would provide clear benefits for prediction research, where context monitoring and cue integration are essential for processing (e.g., Christopher et al. 2012), as well as in bilingualism, where inhibition and context monitoring are necessary to control one’s languages online (cf. Meuter and Allport 1999; Kroll and Bialystok 2013; Green and Abutalebi 2013; de Bruin et al. 2014). Proactive and reactive control may additionally be a promising way to operationalize strategies individuals use to negotiate linguistic variation.
Many models incorporate top-down biases or cue weightings that influence processing (e.g., Dell 1986; Bates and MacWhinney 1989: 42; Dijkstra and van Heuven 2002; Green and Abutalebi 2013). Cue weightings are predominately governed by the speech context or prior experience, and as such would be influenced by proactive control. Other models include some notion of a feedback loop used for error correction or self-monitoring (e.g., Dell 1985; Hickok 2014). This may be modulated by reactive control. A crucial advantage of incorporating measures of proactive and reactive control into psycholinguistic models of language processing is that they can quantify individual differences in processing, allowing generalized models to adapt to idiosyncratic patterns of language use. By means of illustration, I show how dual mechanisms of cognitive control might be implicated in a processing model focusing on the lexical level and below (Dell’s interactive connectionist model). For the time being, it will be left as a challenge to language scientists to test the hypotheses generated by this illustration and unravel how proactive and reactive control can be integrated into other popular models of language processing.

4.1 Dell’s interactive connectionist model

Dell’s (1985,1986, inter alia) speech production model is an interactive connectionist model that utilizes the notions of spreading activation and an interaction of feedforward and feedback mechanisms. At a minimum, the model consists of a collection of hierarchically-ordered nodes linked by four distinct types of connection: two are bottom-up (types a and b), one is lateral (type c), and one is top-down (type d). Type a connections are excitatory, bottom-up connections, while type b connections are bottom-up but inhibitory in nature; the two serve complementary functions. Type c connections are pairwise lateral inhibitory connections used to resolve competition at a given level of processing and halt spreading activation. Finally, type d connections are excitatory, top-down connections that provide positive feedback from higher to lower levels of production and use this information to resolve ambiguity.

Because it incorporates both feedback and feedforward mechanisms as well as activation at multiple levels of processing, Dell’s model integrates readily with dual mechanisms of cognitive control. In this model, success of feedforward mechanisms may be modulated by an individual’s proactive control. For example, individuals operating in a proactive control mode should have stronger feedforward mechanisms. This would bias production based on upcoming context, which may lead to an increase in speech anticipation errors (e.g., leading list for reading list) or exchange errors (e.g., self-instruct de... for self-destruct instruction; cf. Dell 1986: 285). Similarly, feedback mechanisms may be modulated by reactive control. If multiple phones are activated at the moment of lexical selection (e.g., due to sharing features, like /k/ and /g/), reactive control should quickly be engaged to suppress competition. This would predict, for example, that individuals with stronger reactive control would show less neighborhood density effects than those with weaker reactive control. Individuals with low reactive control may also show preservative errors in production (e.g., beef needle for beef noodle; Dell 1986: 285) due to a failure to disengage and reduce activation of the previous phone. These predictions could be reflected in the model by allowing performance on behavioral tasks to influence activation levels of the four connection types, which may in turn create a model that is more representative of experimental data.

5 Implications of control strategies for variation within and across individuals

5.1 Variation and adaptive control

In their seminal paper, Green and Abutalebi (2013) propose that patterns of language use over time may distinctly tune the brain’s cognitive architecture (the ‘Adaptive Control Hypothesis’). For example,
bilinguals who frequently suppress an entire language are hypothesized to have distinct control mechanisms from those who switch languages frequently in the same situational context. Hartanto and Yang (2016) find support for this hypothesis, observing smaller switch costs for bilinguals who regularly operate in dual-language modes compared to bilinguals who traditionally operate in a single-language mode.

The same may be true for local levels of processing (e.g., phonology). Lev-Ari and Peperkamp (2013) found that English-French bilinguals immersed in France produced voiceless stops with a voice-onset time (VOT) more intermediate between English and French monolinguals the weaker their inhibitory control. Crucially, they also found that as length of immersion increased, differences among participants also increased as a function of inhibitory control.

Even within monolingual populations, distinct processing strategies may effect changes in performance. For example, Lev-Ari and Peperkamp (2014) used linguistic and nonlinguistic measures of inhibition to investigate how inhibitory control correlated to the degree of phonological competition in French. The researchers had French monolinguals perform a lexical decision task on stimuli with a voiceless stop where the VOT was either normal or artificially-shortened. Crucially, half of the words had competitors with a voiced stop, which has negative VOT in French, in the same position (e.g., coté ‘listed’ vs. codé ‘coded’). Performance was affected by this manipulation as well as inhibitory control: individuals with weaker inhibitory skill were faster to respond to words with a phonological competitor and shortened VOT. Additionally, the linguistic and non-linguistic tasks correlated with one another, suggesting that the cognitive mechanisms that participants utilized were domain-general.

These findings suggest cognitive control is relevant for category selection, and, crucially, that individual differences in control may produce individual differences in linguistic production over time. Regardless, an approach emphasizing dual mechanisms of control can generate subtler hypotheses regarding the propagation of variation. For example, in Lev-Ari and Peperkamp’s (2014) study, proactive control mechanisms may have been engaged to reduce interference from phonological competitors. In this case, the prediction would be that individuals with strong proactive control should show longer reaction times to intermediate, less-natural VOTs. Reactive control, in contrast, might be invoked after exposure to the stimulus, particularly to intermediate VOTs. Individuals with strong reactive control should more quickly categorize intermediate VOTs and thus show lower reaction times on the lexical decision task.

At the moment of speech, both proactive and reactive mechanisms may be at play and interact. An individual’s tendency to rely on one of these two control mechanisms may consequently affect how he or she processes variation in distinct linguistic contexts, and may have repercussions for how ambiguous tokens are categorized. Crucially, relative usage of one strategy may be advantageous in one context and disadvantageous in another, depending on the demands of the linguistic environment in which one habitually finds oneself. Over time, the Adaptive Control Hypothesis predicts that reliance on one strategy as opposed to the other will affect one’s responses in those and other linguistic environments. Such an account would describe linguistic variation as an emergent phenomenon resulting from a combination of experiential and cognitive constraints on language processing.

### 5.2 Language change

An extreme consequence of the variability in language is language change. Changes-in-progress require individuals to flexibly adapt to subtle modulations of probabilistic tendencies and competition among linguistic distributions in their environment. For example, when sound changes begin, they often preferentially affect certain phonetic environments (e.g., /ei/ raising near /i/ in closed syllables in Philadelphia; cf. Labov 2001: 300). Individuals who first adopt these changes may be those who best distinguish the two variants and the contexts where the novel variant is preferred.

Individuals who best recognize phone/context pairings may also be those who rely on context when processing language. For example, those with weaker proactive control mechanisms may be more easily biased by contextual information than those with stronger proactive control, by virtue of having less
experience engaging top-down control mechanisms to guide processing. This could translate to less perceptual compensation in phone/context pairings, concomitantly resulting in a higher incidence of hypercorrection (e.g., Ohala 1993). Similarly, the linguistic environment of a change-in-progress includes many speakers who completely adopt these changes and others who partially do so. Individuals with stronger reactive control should more strongly compensate for variation in their input, reducing the likelihood of perceiving a novel phone and resulting in a lower incidence of hypocorrection (cf. Ohala 1993). In these cases, proactive and reactive control may work in tandem (stronger mechanisms impede adoption of the change).

In other types of language change, however, proactive and reactive control may work against one another. Consider a syntactic change-in-progress: grammaticalization of the Spanish Progressive (e.g., Torres Cacoullos 2012, 2015; Berry Forthcoming). While English has a zero-marked simple Present that codes for habitual actions (e.g., ‘I write papers’; cf. Bybee 1994), the Spanish simple Present still alternates with the Present Progressive (e.g., Hablo por teléfono vs. Estoy hablando por teléfono ‘I’m talking on the phone’). Over the last century, the Spanish Present Progressive has followed a path similar to English, wherein the Progressive is used more in limited duration contexts (i.e., those wholly circumscribed to or remaining incomplete at the moment of speech). Importantly, use of the Spanish Progressive in extended duration contexts, where English would use the simple Present, is driven by structural priming (cf. Berry Forthcoming).

Here, proactive and reactive control may produce distinct consequences. Proactive control may correlate to one’s tendency to distinguish the functional roles of the two constructions, since usage of top-down strategies would presumably influence variant selection. Using a proactive strategy would bias context toward the intended meaning, which in turn may result in less distinction of the two variants. Strong proactive control is thus hypothesized to result in weaker association of the Progressive with limited duration contexts, and as a consequence, to impede adoption of the change-in-progress. Additionally, weaker reactive control would relate to a decreased ability to react to variation in context, which may lead to greater susceptibility to structural priming. Thus, weaker reactive control may impede adoption of the change-in-progress, since greater susceptibility to priming would result in higher relative usage of the Progressive construction in dispreferred (extended duration) aspectual contexts. For this syntactic change-in-progress, then, the two control mechanisms would be in opposition. Hence, individuals with weak proactive and strong reactive control would be expected to be most advanced in grammaticalization of the Spanish Progressive, individuals with relatively equal magnitudes of each should be less advanced, and individuals with strong proactive and weak reactive control should be the least advanced.

6 Conclusion

Psycholinguistic models of language processing that have historically been modular must incorporate some notion of variation, since language is variable at all levels of representation. Acceptance of variation as an inherent part of language (e.g., Weinreich et al. 1968) allows psycholinguistic models to be more representative of how language is actually used by speakers, more flexible regarding individual processing differences, more inclusive of multiple levels of processing and, importantly, more predictive in light of ubiquitous language variation and change.

Cognitive control, when interpreted in a dual mechanisms approach (Braver et al. 2007), adds predictive power to psycholinguistic models of language processing at little theoretical cost. Because proactive and reactive control are domain-general mechanisms already implicated in work unrelated to language, no additional constructs (e.g., task schemata) need to be postulated in order to account for observed phenomena. AX-CPT provides a simple quantification of proactive and reactive control, which can be combined alongside other modified executive function tasks in both in the laboratory and the field. The inclusion of proactive and reactive control in psycholinguistic work on language processing offers novel,
testable predictions regarding how individual differences in the resolution of variation may affect differences in the structure of language across speakers over time. The average speaker/hearer regularly contends with variation without issue, and psycholinguistic models of language processing must make an effort to follow suit.

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