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An Integrated Language and Memory Approach to Conceptual-Lexical Retrieval

by

Channing Everidge Hambric

A Dissertation

Presented to the Graduate and Research Committee

of Lehigh University

in Candidacy for the Degree of

Doctor of Philosophy

in

Psychology

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An Integrated Language and Memory Approach to Conceptual-Lexical Retrieval

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ABSTRACT

Language production and memory researchers both study the long term effects of semantic retrieval. Both fields have routinely observed the same *semantic interference* phenomenon, in which generation from memory impairs subsequent access to semantically related representations. However, to date there has been very little communication across these literatures and our understanding of conceptual-lexical retrieval is fragmented across fields. In this dissertation I propose that the language production and memory literatures are ostensibly studying different aspects of the same *semantic interference* phenomenon and that an integration of the separate but complementary accounts of conceptual-lexical retrieval is long overdue. Thus the goal of this dissertation was to lay the groundwork for further integrative efforts. I developed a verbal integrated incremental learning account of conceptual-lexical access to serve as a blueprint for future model development and tested a subset of the resulting hypotheses across three empirical components. In Component 1, *Retrieval-Induced Semantic Interference*, I developed a modified version of the retrieval practice paradigm, which would serve as the primary methodology for the dissertation. I shed light on how interference unfolds over time by implementing an internally structured continuous naming design in each phase, and the effect of past generative activity was assessed in the final phase by comparing related picture naming latencies to unrelated experimental controls. The results confirmed that cumulative interference occurs during a standard memory manipulation (category-stem cued retrieval) and that this interference carries forward to a subsequent phase of continuous picture naming. These findings thus use a fine-grained temporal analysis to highlight the common basis of adaptive learning processes and show that related retrieval affects subsequent lexical access, regardless of the specific task. Component 2, *Adaptive Learning After Semantic Interference: Does Interference*

Promote Enhanced Relearning?, explored the memory claim of enhanced relearning (Storm et al., 2008; Hulbert & Anderson, 2015; Ritvo et al., 2019) in which relearning after semantic interference results in heightened accessibility compared to both initial levels and unpunished controls. I examined the unfolding of learning and relearning over generation, relearning, and assessment phases and found evidence for restoration but not enhancement of accessibility for past competitors. This finding calls into question the generality of enhanced relearning and suggests that it may chiefly apply to novel learning contexts rather than acting on preexisting conceptual-lexical networks. Component 3, *Durability and Locus of Retrieval-Induced Semantic Interference*, sought to investigate the durability of retrieval-induced semantic interference and the respective contributions of conceptual versus conceptual-lexical adaptive learning. Experiments 3A and 3B used a continuous picture naming procedure in two phases separated by a short or overnight retention interval to assess the durability of semantic interference as well as the possible role of sleep-based consolidation. In contrast to the prior two components, I only found retrieval-induced semantic interference after nocturnal sleep, and this interference was only manifest as increased production errors. Experiments 3C and 3D explored the origin and locus of retrieval-induced semantic interference. These experiments introduced a novel variation of a pre-lexical picture matching task to elicit conceptual-level as distinct from conceptual-lexical adaptive learning. To assess the impact of this learning, the final assessment phase involved either generative picture naming or a continuation of picture matching. In both experiments, the initial picture matching phase produced cumulative facilitation over each related generation. In Experiment 3C, the following picture naming phase produced cumulative interference, but there was no effect of the previous phase. Experiment 3D did not find significant cumulative processes nor cross-phase facilitation in the final matching assessment

phase. The results of this component indicate that more work is needed to ascertain the durability of interference and that interference may only manifest when lexical retrieval is a required stage of processing. The dissertation concludes with an update of the blueprint for an integrated memory and language production account of conceptual-lexical retrieval. Together, the present work shows that assuming a combined memory-language approach to the study of retrieval-induced semantic interference is not only illuminating, but necessary to fully characterize the dynamics of the conceptual-lexical interface.

Introduction

Communication entails the rapid and flexible exchange of ideas. Although these ideas are drawn from semantic memory, we must map these ideas onto specific lexical representations to communicate these ideas with the social world around us. We are constantly remembering and communicating through words, but the current research is mostly blind to the inextricable connectivity between memory and language. Moreover, one of the most critical features of the cognitive system is its ability to learn from experience, such that we fluidly adapt our cognitive processes to ease future interactions. In both memory and language, semantic similarity often drives these learning processes. Similar items elicit similar patterns of activation (i.e., involve the activation of overlapping, shared features), thereby encouraging fast, generalized responses (e.g., Tenenbaum & Griffiths, 2001). However, this similarity-based learning comes at a cost; the more features items share, the more strongly they will co-activate, sometimes leading to instances in which a strongly coactivated item slows the production of the correct target or is even erroneously selected (see Levelt et al., 1999; Dell, 1986, for general models). Thus, incremental learning mechanisms must strike a balance between generalization and individuation (Coutanche & Thompson-Schill, 2014; Nozari & Hepner, 2018; Rotvi et al., 2019). This balance is especially delicate when we must produce a single response amidst highly coactivated semantic competitors.

Accounts of incremental adaptation to semantic access have been independently developed within the fields of memory and language production. Although they recruit overlapping stages of processing and report seemingly compatible phenomena, there is still markedly little communication between the two literatures. Within the field of memory, research on retrieval-induced forgetting (RIF) has shown that recalling an item from memory spreads

activation to related non-target items, and that these latently activated relatives are thought to be suppressed during retrieval. This suppression affects the long term accessibility of semantic relatives, such that these items are harder to access in the future compared to items that were never activated during retrieval. In parallel, semantic interference in language production shows that participants are slower to find a word for a concept after having recently generated related names, suggesting that lexical access to latently activated semantic competitors is weakened as a result of target retrieval (Howard et al., 2006; Oppenheim et al., 2010). Thus, both accounts point to response difficulty arising from semantically related retrieval. Moreover, both literatures make a distinction between short-term competitive effects (Roelofs, 2018; Jonker et al., 2012) and longer term incremental learning mechanisms that adapt network connections based on experience, albeit at different levels of representation (Norman et al., 2007; Oppenheim et al., 2010; Howard et al., 2006). Given these similarities and the assumption that the respective interference effects arise within a domain-general semantic network, a number of researchers have proposed that a similar (if not a unitary) incremental learning mechanism underlies both retrieval-induced forgetting and semantic interference in language production (Oppenheim et al., 2010; Jeye et al., 2021; Navarrete et al., 2021; Hambric & O'Séaghdha, 2022).

Researchers in the two fields have overlooked that, if both conceptual and lexical retrieval is required for a given task, learning may occur at several possible levels within the system. On the memory side, since the memory tasks in the relevant literature typically entail retrieving individual words from memory, lexical retrieval and selection are required stages of processing. However, memory researchers have disregarded lexical processes and instead conflate linguistic processing with changes to the conceptual representations themselves. Conversely, since retrieving a word requires mapping a set of interconnected semantic features to

a corresponding lexical representation, or *lemma*, changes to nonlinguistic conceptual representations in memory naturally affect the degree of converging activation a lemma receives, thus impacting lexical retrieval and selection. Yet, language production researchers typically assume that conceptual representations are relatively fixed, and that only links to words are modulated by experience. It is possible that the slighted locus of processing may actually be the primary driving force behind the observed phenomena in either literature.

Overview

I suggest that our current understanding of conceptual-lexical retrieval is problematically fractured between the fields of memory and language production. I propose that both semantic interference in language production and retrieval-induced forgetting as studied in the memory literature engage conceptual and conceptual-lexical retrieval processes and that identifying the contributions of learning at each locus is necessary to fully understand semantic interference. Here I will present an aligned framework that provides a novel integration of the two fields. This framework will serve as an initial blueprint for the requirements of an inclusive model of conceptual-lexical adaptation, as well as provide a number of readily testable hypotheses.

In the next sections, I describe the memory-based and language-based studies of semantic interference in turn before presenting key computational models of incremental learning in the two fields. I then propose a novel aligned framework that will be used to guide the empirical components. Following this theoretical framing, I will introduce each of the three primary components of the dissertation. Each component is designed to address specific questions in the aligned framework. Following these components, I will synthesize the findings and implications for future integrated models of conceptual-lexical retrieval.

Semantic Interference in Language Production

In order to produce words within any communicative context, we must first activate the idea we wish to convey. The way in which these ideas, or concepts, are represented differs across theories (e.g., Levelt et al., 1999; Oppenheim et al., 2010, see Kumar, 2021 for review), but most theories now assume that concepts are in some way comprised of distributed semantic features. These features link to the respective lexical representations, or *lemmas*, associated with them. Thus, when we intend to speak a single word, words that share semantic features become coactive as activation spreads (Rapp & Goldrick, 2000). In normal speech, the activation of all of the target specific features converges on a single lemma, such that the target lemma is considerably more active than the other coactivated lemmas. This results in the target word being fluently selected for production. However, when coactivated words share a high number of semantic features, their degree of coactivation is closer, making it more difficult for the system to select the right word for production. These coactivated competitors are thought to be downregulated in order to reduce their chance of being erroneously selected, thus making them harder to access when they are later produced (Oppenheim et al., 2010).

Semantic interference in word production has chiefly been studied using picture-naming tasks that require overt generation of picture names. These tasks involve both conceptual and lexical retrieval and explicit lexical selection (e.g., Schriefers et al., 1990). The key finding is that naming semantically related pictures results in slower naming response times (e.g., Howard et al., 2006; Rose & Abdel Rahman, 2016). Semantic interference has been explained by two mechanisms; short-term competitive lexical selection (Roelofs, 2018; Abdel Rahman & Melinger, 2019), and long-term incremental learning (Howard et al., 2006; Oppenheim et al., 2010; Oppenheim & Nozari, 2021). The short-term competitive viewpoint is often supported by

findings from picture-word and cyclic naming paradigms, in which the semantic relatedness of the immediately adjacent context (either distractor words or members of small sets, respectively) is manipulated (Damian et al., 2001; Abdel Rahman & Melinger, 2011). Evidence for the long-term learning view comes from the continuous naming paradigm. In this paradigm, related set items, often members of a taxonomic category, are presented in an intermixed continuous sequence. Critically, the sequence is internally structured such that related set items appear in each of several sectors so that the effect of *ordinal position* can be assessed (Howard et al., 2006). There is typically a linear increase in naming time across category member ordinal positions, and so this is often termed the *cumulative interference effect* (Howard et al., 2006; Oppenheim et al., 2010; Rose & Abdel Rahman, 2016; see Figure 1).

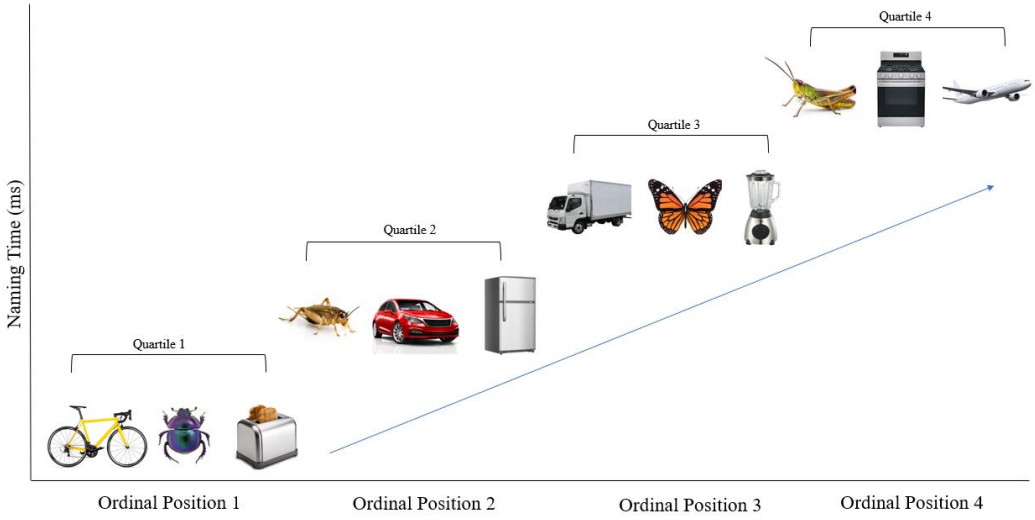

Figure 1. Simplified schematic of a continuous picture naming design (e.g., Howard et al., 2006) with related items distributed in four quartiles. In this particular design, used throughout this dissertation, naming latencies are averaged within each quartile to create an Ordinal Position variable. The figure depicts the typical linear increase in interference with successive Ordinal Positions.

Since the design entails a substantive number of (unrelated) interleaved items between members of the same category, the increase in naming times cannot be attributed to short-term competition and is better accounted for by long-term learning mechanisms (Howard et al., 2006) that strengthen access to selected targets and may also weaken access to unselected competitors (Oppenheim et al., 2010). Also note that some accounts posit that a non-competitive learning mechanism can also account for findings typically attributed to short-term, competitive processing (Oppenheim & Nozari, 2021, but see Belke & Stielow, 2013). However, others have suggested that semantic interference may comprise both short-term competitive processes as well as long-term incremental learning (O'Séaghdha et al., in prep). I assume this diplomatic view here but will chiefly focus on the mechanisms underlying long-term cumulative semantic interference. Cumulative interference is well positioned to help us understand how each production instance is also a *learning* instance, such that the system is constantly updating accessibility based on recent experience. This updating may also involve learning within a conceptual stratum, which is the assumption within the memory literature. Regardless, the key takeaway is that producing words in a context that activates semantically related representations results in semantic interference, which is typically indexed as increases to both production latencies and errors.

Retrieval-Induced Forgetting

It is well known that actively retrieving an item from memory makes that item more accessible in the future (see Roediger & Karpicke, 2006, for review). Active memory retrieval inherently entails the activation of relevant semantic (conceptual) features, many of which are intrinsically shared by multiple category members. As the system selects one target representation from among the coactivated options, future access to this representation is

strengthened (e.g., Schilling et al., 2014). Much like in language production accounts, this learning process is thought to come at a cost to the related, coactivated competitors. Two phenomena have been observed that point to such a trade-off. One, the recall of related items decreases linearly with each generation (e.g., Tulving & Arbuckle, 1963; Roediger & Schmidt, 1980). Second, items from the same category as retrieved items suffer impaired memory access at a later test relative to items from unaccessed categories. Anderson, Bjork, & Bjork (1994) were the first to introduce what is now termed *retrieval-induced forgetting* (RIF), the phenomenon in which it is more difficult to recall items from memory after categorically related memory items have been retrieved (Anderson, Bjork, & Bjork, 1994). The hindered access to semantically related items following retrieval has been extensively studied using the *retrieval practice paradigm* (Anderson, Bjork, & Bjork, 1994; see Figure 2). In this methodology, participants are first exposed to a series of category-exemplar pairs (e.g., INSECTS-beetle, INSECTS-cricket, APPLIANCES-toaster). In a subsequent phase, retrieval for half of the items from a subset of categories is "practiced" using category cued stem-completion prompts (e.g., INSECTS-be____). Note that in this phase, participants are cued to generate each word multiple times to ensure thorough processing. Also, category members are typically dispersed across the sequence similarly to the design of the continuous picture naming experiments. The participant then completes a distractor task (typically for 15-20 minutes) before completing a final task, where they are asked to retrieve all items presented in the initial exposure phase. Recall is either completely free or uses previously presented category cues, and responses are either written or spoken (Anderson et al., 1994; Storm et al., 2006; Coman et al., 2009; Johansson et al., 2007; Jonker et al., 2013).

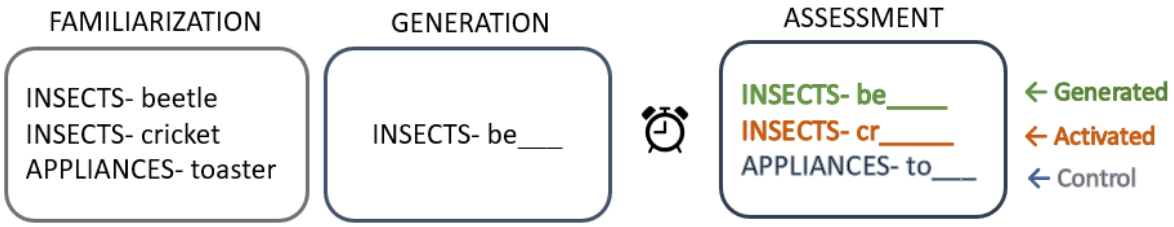

Figure 2. Simplified schematic of a typical retrieval-practice paradigm (Anderson et al., 1994). The typical finding is facilitated recall in the Generated condition, and significantly impaired recall in the Activated condition compared to the nonactivated Control condition.

The design effectively creates three conditions with different types of items: 1) items from a given category that were retrieved during the "practice" (Generation) phase (Generated[1], e.g., INSECTS – beetle); 2) items from the same category as the retrieved items but which were not cued for retrieval (Activated, INSECTS - cricket); and 3) unretrieved items from unused categories (Control, APPLIANCES - toaster; Anderson, Bjork, & Bjork, 1994). Note that for consistency I am using more general terminology adopted in Component 1 below rather than the esoteric acronyms and other labels used in the RIF literature. As one might expect, items generated in the second phase (Generated condition) typically have the best retrieval success rate in the assessment phase. However, the principal comparison of interest is between the Activated and Control conditions. The typical finding is that Activated items are retrieved at a significantly lower rate than nonactivated Control items. According to Anderson, Bjork, & Bjork (1994), during Generation, categorically related representations are activated and compete with the

[1] In the retrieval-induced forgetting literature, the corresponding terms are Rp+ (retrieval practiced) for Generated, Rp- for Activated, and Nrp (no retrieval practice) for the Control condition.

target. These representations are proposed to be inhibited to facilitate target retrieval, thereby resulting in impaired accessibility (compared to Control) at final assessment. Thus, they attribute this retrieval-induced forgetting effect to inhibitory mechanisms that suppress competing representations in a holistic manner. Other theories suggest that RIF might be better explained by contextual cueing mechanisms during the final assessment (e,g., Jonker et al., 2013) or through associative unlearning between the category cue and the Activated items (Melton & Irwin, 1940; see Anderson, 2020 for review). Contrary to the predictions of both of these accounts, the RIF effect has been replicated across a variety of methodological manipulations specifically designed to limit the influence of these cue dependent factors, including variations in which a new cue word without any relation to the practiced cues is used to trigger recall at final assessment (but see Camp et al., 2007; Perfect et al., 2004). In an influential computationally implemented account, Norman et al. (2007) proposed that punitive modulations to latent competitors are indeed the driving force behind forgetting, but previous models were too simplistic and neurally implausible. In their nuanced account, Norman et al. (2007) proposed that a learning mechanism adapts accessibility to concepts at the (micro) feature level. Specifically, this account suggests that, following target retrieval, the intraconceptual links of the target are strengthened while the connections between the competing items' conceptual features are weakened, thereby supporting recall for targets while hindering it for semantic competitors (Norman et al., 2007). Note that this strengthening of target links and weakening of competitor links is broadly consistent with the corresponding learning processes outlined in Oppenheim et al.'s model of incremental learning in language production.

Aligning Language and Memory Accounts

It should now be apparent that retrieval-induced forgetting is directly parallel to cumulative semantic interference in language production (also see Oppenheim et al., 2010; Navarrete et al., 2021). Moreover, I emphasize that a full understanding of either phenomenon requires inclusion of a missing stage of processing that is addressed in only one of the literatures. Language production researchers disregard the possibility that intraconceptual changes impact the subsequent accessibility of selected and unselected lemmas, and current word production models use overly static conceptual representations that have little connection to modern models of semantic/conceptual memory (e.g., Renoult et al., 2019; Lambon Ralph et al., 2017). In turn, models of memory retrieval ignore the complex lexical processes that are required by generative memory tasks. Moreover, conceptual-lexical links are themselves structures stored in memory and may thus be a plausible locus for experience-driven adaptation in tasks requiring verbal generation. The comparative and integrative work needed to link the two fields is yet to be done and is the focus of this dissertation. I propose that aligning the computational accounts of adaptive learning in the fields of language and memory is critical to understand how diverse generative experience shapes conceptual-lexical access. I now describe each of the leading computational models with the aim of developing a unified account that adopts the key mechanistic elements of either model while overcoming their respective limitations. This initial integrated account will provide a testable framework for present and future research.

Two Influential Computational Accounts

Oppenheim et al.'s (2010) 'Dark Side' Model of Incremental Learning in Word Production.

Although it was not the first model developed to account for cumulative interference (see Howard et al., 2006), the widely used "Dark Side" Model of incremental learning proposed by

Oppenheim et al. (2010) goes beyond Howard et al. by implementing error-driven connectionist learning and including a non-competitive lexical selection threshold to simulate latencies as well as both commission and omission errors. That is, while Howard et al. (2006) suggested that semantic interference could be accounted for by strengthening the conceptual-lexical links of selected targets, Oppenheim et al. (2010) also implemented downregulatory learning for unselected competitors. This strikingly simple 2-layer, feed-forward model shows that a long term, error-driven learning mechanism that bidirectionally adapts connective weights between concepts (represented by distributed features) and words based on retrieval experience can account for an extensive range of findings in the relevant language production literature.

Model Architecture. The model has a single learning algorithm with two "sides": one that increases the connection weights from active semantic features to selected word nodes and one decreases weights from those features to unselected competing word nodes (see Figure 3). It also simulates lexical selection latencies through a booster mechanism that iteratively floods the network with activation until a target passes a set threshold, but this aspect is less important for the present purposes. In sum, according to this model, a single learning mechanism strengthens successfully chosen targets and weakens unselected competitors (Oppenheim et al., 2010).

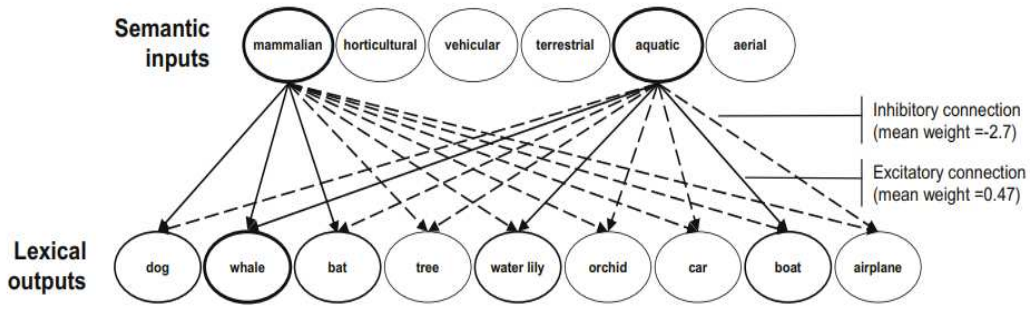

Figure 3. Dark-side model of semantic interference in language production (Figure 2, in Oppenheim et al., 2010).

I will now walk through the model using the examples from Figure 2. If a participant names *beetle* in ordinal position one (see Figure 2) in a continuous naming sequence, the connective weights between the relevant semantic features and the lemma *beetle* would be strengthened, while weights between these shared features and latently activated lemmas, such as *cricket* and *butterfly*, would be weakened. As a result, if *cricket* is to be named at ordinal position two, it takes more time for the activation of the recently punished target to reach the selection threshold. Following production, the learning algorithm strengthens the connections to *cricket*, as well as weaken the connections to latently activated competitors, including *butterfly* and the previously selected *beetle.* It follows that when *butterfly* is to be named at ordinal position three, it is even *harder* to access given that it was weakened when naming both *beetle* and *cricket,* and so even more time is needed to surpass the selection threshold. Effectively, this results in an increased response latency (modeled as number of boosts) as ordinal position in the continuous naming sequence increases, regardless of the number of unrelated intervening items. In this way, cumulative interference is proposed to be insensitive to time and may only dissipate with relevant production experience.

Simulations. To test the model, Oppenheim et al. (2010) conducted a number of simulations. They found that the model was able to recreate previously observed patterns across both the continuous and cyclic naming tasks (which entails naming small sets of related or unrelated pictures), as well as replicate the results of previous studies examining generalization of interference to new items (Belke et al., 2005) and the error patterns produced by aphasic patients (Schnur et al., 2006, 2009). Perhaps most importantly, one simulation showed that while the learning algorithm is competitive in the sense that the magnitude of punitive changes depends on the degree of competitor activation, a competitive selection mechanism is not necessary.

Rather, Oppenheim et al. (2010) found that the model produced equivalent results whether the target activation is compared to that of the strongest competitor or to a set threshold, suggesting that it is incremental learning, rather than competition for selection, that drives cumulative interference. This claim has been controversial, and is still heavily debated (Oppenheim & Nozari, 2021; Roelofs, 2018; Abdel Rahman & Melinger, 2019; Piai et al., 2012).

The results of another simulation (Simulation 5) are also highly relevant to the current discussion. In this simulation, Oppenheim et al. make a direct connection to the "occlusion versus inhibition" debate in the RIF literature. This debate concerns whether forgetting is primarily driven by strongly activated Generated items (see Figure 2 for example) somehow blocking access to related Activated items that share the same category cue (e.g., MacLeod et al., 2003) or by downregulation of the Activated items themselves (e.g., Anderson, 2003). To evaluate these alternatives, Oppenheim et al. (2010) compared two iterations of the model in the context of the cyclic naming task. One version of the model included only target strengthening, while the other included only competitor weakening. They found that the target-strengthening-only model showed the typical pattern of decreased latencies over repeated cycles, but there was no effect of relatedness. In contrast, the competitor-weakening-only model exhibited a strong relatedness effect, but there was no repetition benefit. They concluded that while target strengthening is certainly a part of the natural dynamics of lexical selection, competitor weakening is the primary driving force behind semantic interference (Oppenheim et al., 2010). These results also imply that competitor downregulation underlies the "forgetting" of Activated items in the RIF paradigm, and they suggest that cumulative interference and RIF share key characteristics.

Norman et al.'s (2007) Neural Network Model of Retrieval-Induced Forgetting

This model retains much of the behavioral assumptions of an inhibition-based account proposed by Anderson (2003) but implements competitor downregulation by modulating intraconceptual links. Specifically, an algorithm raises network-wide inhibition above and below a predetermined threshold to identify weak aspects of the target memory and strong aspects of competing memories before implementing a Hebbian learning mechanism to strengthen these connections within the target and weaken them within competing representations (Norman et al., 2007). Note that in this case, inhibition refers to the activity of inhibitory interneurons that impose a set activation threshold to prevent activation from spreading throughout the network, not the lateral inhibition of holistic concepts proposed by Anderson et al. (1994).

Model Architecture. The model contains episodic and semantic layers to model both intraconceptual and contextually mediated learning. The semantic aspect is composed of two layers, including fully connected "associative" and "item" layers, which computationally allow for the representation of the category-item pairs used in RIF procedures. The associative layer corresponds to the representation of a category cue, whereas the pattern of activation in the item layer represents the specific exemplar. Each of these layers is fully connected to representations in both a broader hippocampal layer and a separate context layer. The hippocampal layer is used to represent broad episodic experience by memorizing patterns of semantic activity to support later pattern completion, while the context layer represents task-specific experience (Norman et al., 2007). The same form of oscillation and learning is applied to both associate and item layers within the semantic layer, within the episodic layer, the context layer, and to the connections between them.

The learning process consists of several stages, see Figure 4. First, the pattern of a specific target is presented to the network, and a baseline resting level of activation is established. Second, an algorithm identifies weak parts of the target memory by raising inhibition above this threshold, and identifying which features are the first to become inactive. The Hebbian learning procedure then strengthens the connections between these weak features and other activated target features, thereby supporting future pattern completion for the target. Next, the algorithm identifies overly strong aspects of competing items by seeing which features of competitors become active when inhibition is lowered below the baseline threshold. Finally, the same learning mechanism then weakens the connections to these units, thereby making it more difficult to retrieve the items in the future. Note that, as in the Oppenheim et al. (2010) model, a single (but two-sided) learning algorithm captures both target strengthening and competitor weakening, but impaired retrieval is due to the weakening of laterally connected conceptual feature links rather than modulation to links between features and lemmas.

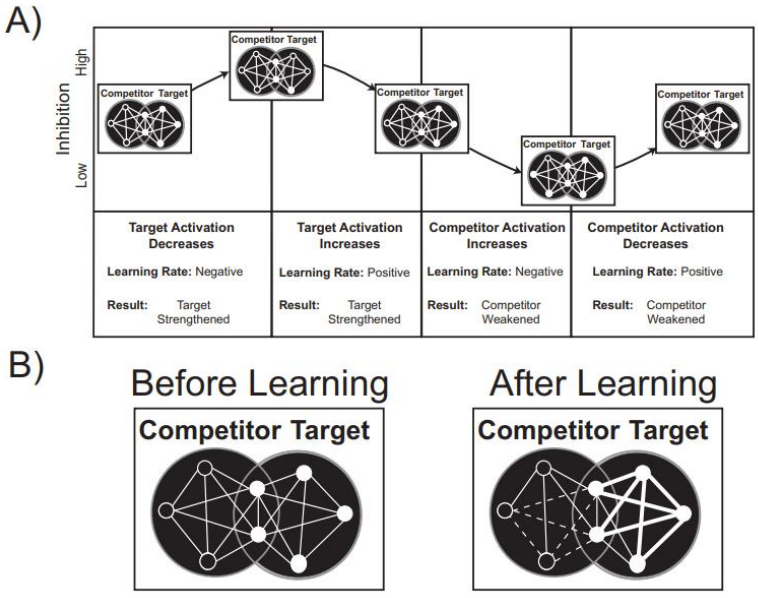

Figure 4. Overall dynamics of the neural network model of retrieval-induced forgetting (Figure 5, from Norman et al., 2007).

I'll now walk through the model with an example (same items from Figure 2). Say a participant in a simulated retrieval-induced forgetting experiment is shown a list of category-exemplar pairs including *INSECTS - beetle, INSECTS - cricket,* and *APPLIANCES - toaster.* In the model, the categories are represented in the more abstract associate layer, while the exemplars are represented in the connected item layer. During the Generation ("practice") phase, *INSECTS - beetle* is cued (i.e., INSECTS - be____). In the model, cued retrieval is simulated by presenting a partial pattern of activation to the network and indexing whether the network was able to successfully complete the pattern. Following pattern completion, oscillating inhibition identifies and strengthens connections to the weakly activated aspects of *beetle*, thereby making it easier to retrieve in the future. In addition, the model identifies and weakens connections between the activated features of latent competitors such as *cricket*, making it harder to retrieve compared to the unactivated control *APPLIANCES - toaster.* At final test, partial patterns are again presented to the network. If pattern completion meets the predetermined threshold when the cue is presented, it is coded as a successful retrieval. Note that the model outcome is thus binary and does not track the time course of pattern completion, but I suggest such a temporal component could readily be integrated into the Norman et al., (2007) model.

The model produced retrieval induced forgetting across a range of manipulations and simulated retrieval-dependence (the finding that forgetting only follows generation from memory) and cue independence (the finding that competitor forgetting does not depend on the specific related cue used to trigger retrieval). It also produced a nonmonotonic effect of semantic similarity such that downregulation (and thus interference) was greater when the target was "just barely" selected over related competitors (Norman et al., 2007, see also Ritvo et al., 2019).

A Unified Framework : Blueprint for Future Models of Conceptual-Lexical Access

By now it should be clear that semantically related retrieval drives long-term changes in competitor accessibility, and that distinct incremental learning accounts have been proposed within the language production and memory literatures (see e.g. Navarrete et al, 2021, for similar observations). Thus far, only one exploratory study has attempted to empirically examine the common neural underpinnings of cumulative interference and RIF using fMRI measures, but they did not find any significant overlap in the regions of interest (de Zubicaray et al, 2015). Regardless, we have parallel sets of empirical findings and two mechanistically similar incremental learning models with virtually no direct empirical comparisons between them. The current lack of comparison is compounded by the fact that the respective literatures differentially focus on continuous latencies (language) versus categorical (memory) measures. In addition, since the tasks used in the memory and language production literatures necessarily involve both conceptual and lexical retrieval, the role of one stage of processing may be falsely conflated with the other in each literature. Where do we go from here?

Here I present what I will refer to as a "blueprint" for an integrated account of conceptual-lexical access. First, I will present what an integrated model must contain to appropriately account for conceptual-lexical adaptive learning. I will then present a side-by-side comparison of the theoretical assumptions held by the pre-eminent language and memory accounts. Given that there have been so few direct empirical comparisons to date, common assumptions are viewed as testable hypotheses of an aligned account rather than confirmed characteristics of adaptive learning. I will then detail the unaligned factors and open questions, which are also viewed as testable hypotheses. A subset of these hypotheses will then be

addressed in each Component of the dissertation. I will then use the results of these Components to inform the prescriptions for future models.

Key Characteristics of an Integrated Account

Levels of Representation. As discussed previously, language production models feature exceedingly simplistic semantic representations whereas models of memory neglect consideration of lexical pathways. Given that speaking entails the mapping of semantic concepts to given words, a sophisticated representation of semantic memory should be implicit in any model of conceptual-lexical access. In turn, the majority of memory retrieval research is conducted using either comprehended or produced verbal stimuli, such that lexical retrieval and selection are often necessary components of recall. Unsurprisingly, I thus assert that an integrated model of conceptual-lexical access should also contain explicit, fully connected lexical representations.

There remains some disagreement about what levels of representation are necessary to capture conceptual-lexical adaptive learning. In Oppenheim et al. (2010), following earlier work by Dell et al. (1997), distributed semantic features map directly onto lemmas. Oppenheim et al. (2010) thus propose that adaptive learning modulates the weight of the links between features and lemmas. In contrast, the account developed by Belke (2013) subsumes the assumptions of both Levelt et al. (1999) and the Featural and Unitary Semantic Space (FUSS) model of Vigliocco et al. (2004) in that features map directly onto lexical concepts. These lexical concepts correspond to a non-lexical collection of semantic features, and these unitary nodes map directly onto lemmas. In the view of Belke (2013), semantic interference arises due to modulated links between distributed semantic features and lexical concepts. It is worth considering that in the FUSS model, these lexical concepts are represented amodally. The idea that modal features are

represented distinctly from amodal integrative concepts is also consistent with the "hub and spoke" model of semantic memory developed by Rogers and colleagues (e.g., Rogers et al., 2004). According to their view, different types of semantic features are represented by different modal "spokes" distributed across the cortex, but these sites feed into an amodal "hub" within the anterior temporal lobe (see Patterson et al., 2007 for review). The purpose of this hub is to integrate information across modalities and form amodal associations between different pairs of attributes within a single network. In this way, lexical concepts are quite similar to the amodal hub representations described by Rogers et al. As also suggested by Wei & Schnur (2016), it remains possible that it is the links between modal semantic features and these amodal, holistic conceptual representations that are modulated by experience and thus drive semantic interference. At the present juncture, it remains possible that adaptive learning acts directly on the links between features and lemmas, on the links between features and amodal (lexical) concepts, or both. I thus propose the inclusion of both and suggest that future models should seek to clarify the theoretical contributions of either locus.

In addition, recall that the model of Oppenheim et al. (2010) comprised a simple 2-layer feedforward network, whereas the highly complex model by Norman et al. (2007) entailed bidirectionally connected but separate hippocampal and semantic networks. The semantic network itself was comprised of two layers in order to directly simulate the retrieval practice paradigm, and a separate context layer was added to index the surrounding episodic context. In this way, the model of Oppenheim et al. (2010) may be underspecified, whereas the complex model developed by Norman et al. (2007) may be over specified. Ideally, a given model should not be so parsimonious as to be implausible but not so overly specified that it cannot be generalized beyond a single task.

Adaptive Learning. Language production models of adaptive learning posit that the links between either features and lemmas or between features and (amodal) lexical concepts are modulated based on recent experience. In contrast, the model of Norman et al. (2007) posits that retrieval-induced forgetting reflects adapted connectivity between the microfeatures that collectively represent a given concept. Based on the present body of research, I suggest that it is possible, if not likely, that incremental adaptive learning may concurrently act on either form of representation. I therefore propose that future models should include adaptive learning at both conceptual and conceptual-lexical levels until more definitive evidence is collected. The final component of this dissertation will focus on estimating the relative contribution of intraconceptual versus conceptual-lexical adaptive learning.

The actual algorithm for implementing adaptive learning in Oppenheim et al. (2010) and Norman et al. (2007) is quite similar. In Oppenheim et al. (2010), weights between features and selected words are strengthened to the degree of the discrepancy between the current and desired states of activation. In turn, the weights between shared features and competing words are weakened to the degree that they exceed the desired resting state of activation. In Norman et al. (2007), an oscillating inhibitory mechanism is used to identify inadequately activated target features and overactivated competitor features. The connections to under activated target features are strengthened to the degree that they are currently discrepant, whereas the connections among overactive competitor features are weakened to the degree that they were overactive. I thus propose that a similar adaptive learning rule is enacted at each locus of learning within an integrated account. It is possible that learning may operate under slightly different parameters at different levels of the network, but further specification of these algorithms is beyond the scope of the present work.

Aligning Specific Claims

I will now discuss the common assumptions of the Oppenheim at al. and Norman et al. theoretical accounts of incremental learning before discussing areas of divergence and open questions. Table 1 provides an overview of the alignment of the accounts.

Commonalities. The core empirical finding is identical across the two literatures: retrieving an item (word) from memory makes it more difficult to retrieve related items in the future. A number of further assumptions have been proposed and supported by both new empirical studies and computational simulations in each literature. Most of these extensions have counterparts in the other literature.

Retrieval Dependence. Perhaps the most reliably observed finding in the memory literature is retrieval dependence. This assumption states that retrieval from memory during the generation phase is necessary to observe forgetting of latently activated competitors. Critically, merely being exposed to (e.g., reading) category-exemplar pairs does not incur any lasting consequences for competitors (Anderson 2003; Norman et al., 2007; Murayama et al., 2014; Storm & Levy, 2012). This assumption is mirrored in the language production literature and is simulated in Oppenheim et al.'s (2010) model where lexical retrieval is necessary to elicit interference. In the Language Production Lab at Lehigh (O'Séaghdha et al., in prep; see also Belke, 2013), a between-subjects manipulation compared cumulative interference in the continuous picture naming paradigm to a word naming condition where the name was presented with the picture. We observed the typical cumulative interference effect in the picture-naming (generation) condition, but no such effect in the word naming condition. Thus, actual retrieval, rather than mere exposure or articulation, is a key requirement of semantic interference in both accounts.

Table 1. Alignment of the methods and findings of language production (cumulative semantic interference) and memory (retrieval-induced forgetting) accounts of semantic interference, as exemplified by Oppenheim et al.'s model of incremental learning in language production and Norman et al.'s neural network model of retrieval-induced forgetting.

	Cumulative Semantic Interference	**Retrieval-Induced Forgetting**
Aligned Factors		
Retrieval Dependence	Yes	Yes
Cue Independence	Yes	Yes
Unitary Learning Rule	Yes	Yes
Temporal Durability	Yes	Yes
Unaligned Factors		
Outcome of Interest	Latencies (RT), Errors, One Phase, No Control Comparison	Retrieval Rate, Multiphase, Related Retrieval Compared to Control Group
Locus of Modulation	Conceptual-Lexical Links	Intra-Conceptual Links
Open Question		
Graded Effect of Similarity	Monotonic (Linear)	Nonmonotonic (U-Shaped)

Cue Independence. The assumption of cue independence, in which the forgetting of latent competitors is independent of the cue used at retrieval, is primarily discussed in the field of memory and is more disputed than the assumption of retrieval dependence. Although a number of researchers have observed cases in which forgetting depended on the same cues being used at Generation and final test, (e.g., Camp et al., 2007; Perfect et al., 2004), others have found a RIF effect with independent probes (e.g., Anderson & Spellman, 1995; Weller et al., 2012, Hulbert et al., 2012). In language production, Oppenheim et al. (2010) state that semantic interference should be observed in tasks in which lexical retrieval and selection occur, regardless of what triggers this process. Though it may be generally accepted, little experimental language production work has directly tested this assumption to date (but see Wheeldon & Monsell, 1994).

Unitary Learning Mechanism. Facilitation and interference occur in both models as a function of a broadly similar learning algorithm. In both cases, learning is driven by the discrepancy between a desired and undesired (i.e., erroneous) network state, and whether a given connective weight is strengthened or weakened depends on the direction of the discrepancy. In this way, target strengthening and competitor punishment are complementary learning processes, or "two sides of the same coin" (Oppenheim et al., 2010). This has a number of implications, and in some instances, may actually be inconsistent with empirical findings (see below).

Temporal Durability. One of the hallmark findings of Howard et al. (2006) was that cumulative interference is not sensitive to varying lags between related items within a sequence, suggesting that the effect cannot be explained by short-term competitive processes. Oppenheim et al. (2010) more explicitly stated that cumulative interference only dissipates through new experience, and not as a function of time. I note briefly that Schnur (2014) did not find cumulative interference at excessive lags of unrelated items, while other accounts do not even

predict durable interference effects (Roelofs, 2018). Thus, the persistence of cumulative interference is still under some debate and more work is needed to test the assumption that cumulative interference is insensitive to time and decays only with relevant production experience. This issue will be addressed in Component 3.

Likewise, Norman et al. (2007) assumes temporal insensitivity, but the actual evidence regarding longevity is also mixed. Some work has shown that forgetting of latently activated competitors persisted even when the retention interval between the generation and test phases was up to one week (Storm et al., 2012; Tandoh & Naja, 2007), while others have found that RIF vanishes after 24 hours (MacLeod & McRae, 2001). MacLeod & McRae (2001) suggested a possible resetting mechanism during sleep to account for disappearance of RIF, but other findings are inconsistent with this interpretation. For example, Abel & Bäuml (2012) used 20 minute and 12 hour retention intervals with and without sleep. They found stable RIF effects in both sleep conditions with the 20 minute interval, but only observed RIF in the 12 hour condition when nocturnal sleep occurred during the interval. These results contradict the notion of sleep-based consolidation as a "resetting" mechanism, and instead suggest that consolidation is necessary to *maintain* retrieval-induced forgetting. This issue of longevity was taken up in Component 3 of the dissertation.

Divergences

Outcome of Interest. Perhaps the biggest obstacle to the direct comparison of cumulative interference and RIF is that the respective literatures focus on distinct outputs. The cumulative interference literature primarily examines the change in picture-naming latencies across ordinal positions within a continuous sequence (Howard et al., 2006). Although it is assumed that downregulation is long lasting, interference is usually only assessed across related positions

within a single phase. In addition, since the continuous sequence is comprised of intermixed sets of related items, each item in the sequence is semantically related to (usually) three other items in the sequence. This lack of control makes it difficult to separate out the effect of related generation from overall task effects. Lastly, due to the relative ease of the task, errors are typically quite low and often not formally analyzed (but see original report by Howard et al., 2006). In contrast, the RIF literature assumes that competitors are downregulated during an initial Generation Phase, but researchers primarily focus on the proportion (percentage) of items successfully retrieved in each memory condition during a later test phase. It is surprising that the Generation phase is never analyzed outside of reporting successful generation rates and we actually know very little about the temporal dynamics of the process that gives rise to later forgetting. In addition, the key comparison in the final phase is between items related to previously generated items (Activated condition) and unrelated controls, thereby providing an empirically rigorous test of the effect of prior related generation. In this field, response latencies are rarely reported, let alone analyzed (but see pioneering work by Brown, 1981, reviewed in Component 1 below; also Coman et al., 2009; Roman et al., 2009). In sum, the behavioral metrics of the paradigms are not readily comparable, regardless of the similarity of the underlying processes.

Turning to model outcome comparability, Oppenheim et al. (2010) use the number of boosts required before lexical selection occurs as an index of naming response time. Notably, this model does have a "time out" function, such that an omission error is registered if a set number of boosts is exceeded. In contrast, the Norman et al. (2007) model has no mechanism to model the time it takes for retrieval to occur, merely whether or not the target pattern was successfully completed after receiving partial input. The model only employs time step

functionality when modeling the oscillating inhibition utilized by the post-retrieval learning algorithm and has no implementation of response latencies.

Locus of Modulation. As previously stated, although the functionality of target strengthening and competitor weakening across paradigms is quite similar, they are proposed to have different placements in the conceptual-lexical network (see Figures 3 and 4). Cumulative interference is thought to arise due to modulations to the connective weights linking conceptual features and words (lemmas), whereas RIF is attributed to modulations to the connective weights linking conceptual (micro)features to one another (see Oppenheim et al., 2010; Norman et al., 2007). As discussed earlier, I briefly note here that some working models in language production suggest that adaptive learning acts on connective links between conceptual features and higher level *lexical concepts* rather than *lemmas* (Belke, 2013). It is possible that this is a distinction without a real difference for the present purposes. I will largely be agnostic to this distinction in Components 1 and 2 but will return to the issue in Component 3. Regardless, it is possible that a similar form of incremental learning applies to multiple types of connections within the conceptual-lexical network. More broadly, Oppenheim et al. (2010) state that, "...[semantic interference] is a general theme in the way the mind operates, independent of the particular types of representation in use" (pg. 250). Although Oppenheim et al. (2010) assumed the same type of learning occurred in non-shared networks, it is reasonable to assume that effects based on language use or non-linguistic retrieval presumably arise in the same network of semantic representations. It follows that changes to conceptual feature connectivity (and changes to nonlinguistic memory more broadly) impact lexical accessibility, see Figure 5. In Component 1, I predicted that generation of related items from memory would result in impaired picture naming for latent competitors. This is thus a key initial finding needed to show that both tasks

engage conceptual-lexical learning and would provide initial evidence that a shared incremental learning network may contribute to both retrieval-induced forgetting and semantic interference in language production.

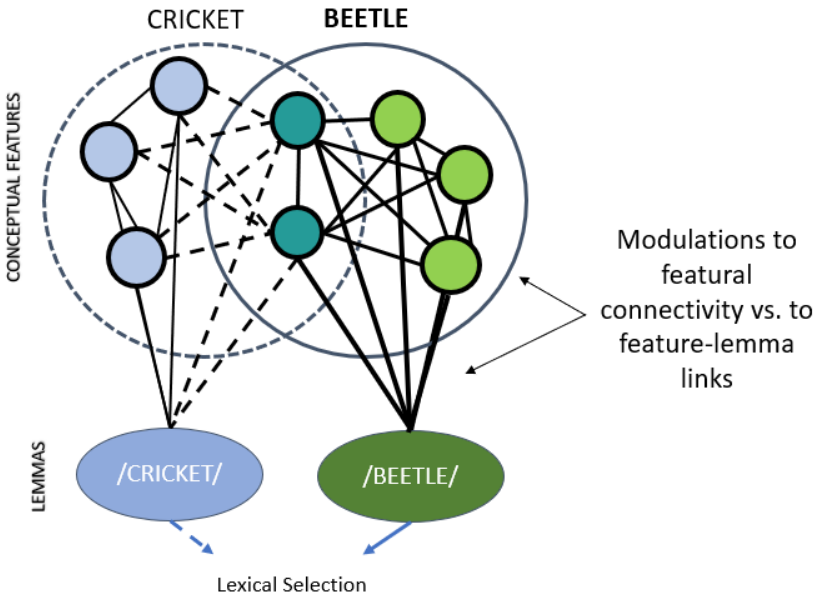

Figure 5. Simplified illustration of the respective loci of semantic interference in language production and retrieval-induced forgetting accounts of Oppenheim et al (2010) and Norman et al. (2007). In language production, modulations are assumed to act on feature-lemma links, while in the retrieval-induced forgetting account modulations are assumed to act on links between conceptual features. The figure represents the changes following the generation of the target *beetle.* Solid, bolded lines refer to strengthened inter-feature and feature-lemma links, which both support future access to the target. Broken lines refer to corresponding weakened intraconceptual or feature-lemma links for the competing representation *cricket,* either of which may hinder future access to the competitor.

An Open Question

There are a number of open questions that arise during the alignment of these two literatures, but here I will focus on one that has especially important implications for future models.

Graded Effect of Similarity. The differences in how the key models handle semantic similarity may seem subtle, but they have important implications. Both models propose a graded effect of similarity, but Oppenheim et al. (2010) suggest that the effect of semantic similarity on competitors is monotonic, with interference increasing linearly with semantic similarity (see Rose et al., 2019 for supporting evidence). In contrast, Norman et al. (2007) suggest that there is a *nonmonotonic* effect (roughly parabolic) of semantic similarity on interference, such that increasing semantic similarity increases interference to a certain point before it decreases and eventually becomes facilitative (see also Ritvo et al., 2019). This is in agreement with Anderson et al.'s finding that high semantic overlap or excessively repetitive paired learning of targets can reduce or even reverse interference (Anderson & Spellman, 1995; Goodman & Anderson, 2001).

The specifics of the nonmonotonic account of learning have been more explicitly stated in the Nonmonotonic Plasticity Hypothesis (NMPH) (Ritvo et al., 2019; Newman et al., 2010; Detre et al., 2013). This account makes large-scale claims about the role of neural integration and differentiation in semantic memory and so has important implications for both the RIF and cumulative interference literatures. The account proposes that when semantically related items are strongly coactive (due to high intrinsic similarity or explicit episodic binding), integration processes increase the representational overlap of these items and promote behavioral facilitation. However, when a related item is only moderately activated, the nonmonotonic plasticity account proposes that the representation of this competitor is weakened overall but also

differentiated from the coactivated target by strengthening connections from shared to competitor-specific features. This overall weakening is thought to be the chief mechanism underlying RIF.

The proposed differentiation has interesting implications for long-term fate of punished latent competitors. It has been proposed that differentiation actually enhances the relearning of punished competitors relative to items that were not subjected to downregulation (Ritvo et al., 2019). Some tentative evidence of such enhanced ("accelerated") relearning after punishment has been found by a number of researchers (Storm et al., 2008; Hulbert & Norman, 2015; Schapiro et al., 2012; see Wammes et al., 2021 for review). Storm et al. (2008) was the first to find that re-encountering previously punished Activated items led to a marginal recall benefit, and subsequent behavioral and fMRI work by Hulbert & Norman (2015) found that heightened accessibility of previous competitors was also associated with decreased pattern similarity in hippocampal regions, suggesting that neural differentiation combined with subsequent strengthening could be the basis of enhanced relearning. I note that Hulbert & Norman (2015) used a more episodically mediated name-learning paradigm, and that differentiation processes may occur with such novel learning more than within the well-established networks of the lexicon.

What implications does this have for semantic interference in language production? The incremental learning account of Oppenheim et al. (2010) assumes that the conceptual-lexical links of features not shared by the target and competitor are unaltered. This clearly contrasts with the nonmonotonic plasticity account in memory, in which connectivity to non-shared features is also altered based on experience. Moreover, differentiation processes involving nonshared features are proposed to drive heightened accessibility when they are relearned after interference.

Enhanced relearning has not been examined in the language production literature. The internal dynamic of both learning and relearning in conceptual-lexical access will thus be examined in Component 2.

Overview of Empirical Components

The core of the dissertation is comprised of three experimental components. The components were designed to test specific parameters of the aligned framework presented above. The first component, *Retrieval-Induced Semantic Interference,* was designed to serve as an initial proof of concept of the idea that many of the same processes are engaged by both retrieval-induced forgetting and semantic interference in language production. This experiment also pioneered a novel semantic interference methodology that paired the careful experimental control of the retrieval practice paradigm with the structured latency assessment of the continuous picture naming task. This design provided the first exploration into the temporal dynamics thought to drive suppression during the Generation ("practice") phase in a typical RIF procedure, and critically, explore how these changes manifest as latency differences in a subsequent phase of picture naming. The experiment thus used different cues during Generation (category-stem completion cues) and the Final Assessment Phase (picture cues), thereby also serving as a new test of the shared claim of cue independence. The second component, *Adaptive Learning After Semantic Interference: Does Interference Promote Enhanced Relearning?,* revisited the question of enhanced relearning using the integrated conceptual-lexical toolbox developed in the prior component. Enhanced relearning has been supported by more recent neuroimaging evidence and the Nonmonotonic Plasticity framework (Ritvo et al., 2019), which proposes that a moderate degree of coactivation (i.e., similarity) is associated with concurrent differentiation processes during learning. It has been proposed that it is this differentiation that

drives enhanced relearning of past competitors (Hulbert & Norman, 2015). However, there is limited evidence that this enhancement applies to well-learned conceptual-lexical representations. If found, this would suggest that the nonmonotonic plasticity proposed by Ritvo et al. (2019) should be incorporated into the integrated model. The last component, *Durability and Locus of Retrieval-Induced Semantic Interference,* addressed two basic but under researched issues central to the integrative effort. Two sub-experiments (3A and 3B) examined the temporal durability of interference in picture naming with retention intervals of either 15-minutes or up to a whole day, the latter including nocturnal sleep. It is possible that sleep-based consolidation processes aid in preserving adaptive learning, such that interference would be equivalent across the two interval conditions. The two other sub-experiments (3C and 3D) were originally conceived as parallel versions of A and B, but with a non-lexical picture matching task in the initial learning sequence. This picture matching task was a novel continuous variation of the procedure originally developed by Campanella and Shallice (2011) and tested by Wei and Schnur (2016). However, after the surprising results of an initial pilot experiment, it seemed more fruitful to replace the retention interval manipulation with a test of a novel question regarding the role of lexical processing in the final Assessment Phase. This issue will be addressed at length in Component 3. Following this adjustment, Experiment 3C implemented the pre-lexical picture matching task in the initial Learning Phase and implemented generative picture naming in the Final Assessment Phase. In contrast, Experiment 3D also used the picture matching task in the initial Learning Phase but sought to separate out the role of lexical processing in interference by using another phase of pre-lexical picture matching in the Final Assessment Phase.

After the presentation of the three Components, the General Discussion will synthesize the key findings and open questions from each experiment. I will then return to the integrated model blueprint laid out earlier. I will specify how the specific results of each experiment should be used to inform future models and provide recommendations for future work.

The organization of these components is as follows. Each component is written in an independent journal article format. Component 1 (*Retrieval-Induced Semantic Interference*) and Component 2 (*Adaptive Learning After Semantic Interference: Does Interference Promote Enhanced Relearning?)* are currently under review. The results and implications for the integrated account of conceptual-lexical access are synthesized in the General Discussion that follows.

Component 1: Submitted Manuscript

Retrieval-Induced Semantic Interference

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Abstract

The long-term negative effect of semantic retrieval on the subsequent accessibility of related material has been extensively studied in separate memory and language production literatures. Though ostensibly studying the same phenomenon, these literatures have remained separated by different framings and methodologies. We argue for integration of the two research streams in an adaptive learning perspective and present a bridging experiment as a proof of concept of this approach. The experiment implemented a multiphase *retrieval-induced forgetting* (RIF) design (with generation and memory assessment phases) in combination with the use of naming latency measures and the temporal analysis of interference featured in language production research. The generation phase, typically unanalyzed in the memory literature, examined generation time for category-stem completions as a function of ordinal positions of related items. There was strong cumulative interference in generation latencies in the first pass though the structured list, showing that memory is already affected in this phase. After a retention interval, accessibility of new items from previously activated categories and unactivated controls was assessed using continuous picture naming rather than aggregate memory measures. Crucially, there was a picture naming cost to previously activated (but not generated) category members relative to the control condition, a RIF effect. This cost was supervenient on new cumulative interference in the assessment phase, underlining the value of the combined methodology. The findings add important detailing to the processes underlying retrieval-induced costs in memory research while also showing that retrieval-induced semantic interference transfers from stem-completion to picture naming retrieval tasks. This format-independence is consistent with a conceptual basis of semantic interference but does not preclude a locus of adaptive learning in conceptual-lexical links. Overall, we show that the memory and

language production fields are indeed different but complementary perspectives on the same semantic interference phenomenon. Combining the fields promises to be productive.

Retrieval-Induced Semantic Interference

The compartmentalization of scientific knowledge is so often lamented that it could be concluded that this seemingly undesirable property is an inevitable concomitant of how focused scientific discovery operates (see Merton, 1961). But when the overlap between separate fields of investigation becomes evident, integration of the complementary explorations is called for. This article examines a particular case, long-term semantic interference resulting from generative activity, where parallel research efforts in language production and memory retrieval research sectors have remained stubbornly separate despite their seeming complementarity. Although this compartmentalization has not prevented important and fundamental discoveries in each field, we argue that separation is no longer justifiable. The segregated discoveries are overdue for integration into a larger memory-language framework that accommodates the discoveries of each subfield, aligns their frameworks, and points to future synthetic directions. We present a proof-of-concept experiment that adopts language production procedures in a multi-phase *retrieval induced forgetting* design in support of the case for an integrated adaptive learning approach to semantic interference.

Semantic interference has been studied independently in subfields of memory and language production for decades using framings and procedures that obscure the underlying commonality between the fields. Semantic activation is principally facilitatory, such that the connections between concepts and words related to generated or comprehended meanings are coactivated through spreading activation processes (e.g., Collins & Loftus, 1975). Although simple priming paradigms show that facilitation is fleeting, other work has shown that semantic relatedness can induce long-term facilitation under certain conditions (e.g., Joordens & Becker, 1997; Becker et al., 1997), or selectively strengthen the accessibility of particular conceptual-

lexical mappings (Rodd et al., 2004; Rodd et al., 2013; Rodd et al., 2017). These findings suggest that strengthened access in comprehension is the result of long-term learning mechanisms rather than mere coactivation. Crucially, in circumstances involving the generation of meaning, long-term adaptation results in both strengthening of selected meanings and downregulation of unselected, coactivated meanings (Norman et al., 2007; Oppenheim et al., 2010). Specifically, generation strengthens access to retrieved meanings and induces interference to related material in tasks such as memory retrieval or picture naming in which a single option is selected from among multiple coactivated conceptual-lexical alternatives (e.g., Anderson et al., 1994; Norman et al., 2007; Schnur et al., 2009; Oppenheim et al., 2010). Separate memory (retrieval-induced forgetting) and language production (especially continuous picture naming) literatures show that the accessibility of conceptual-semantic or linked lexical representations varies as a function of recent retrieval experience (e.g., Brown, 1981; Johnson & Anderson, 2004; Howard et al., 2006; Norman et al., 2007; Schnur et al., 2009; Oppenheim et al., 2010; Anderson & Hulbert, 2021). Although a number of language production researchers have pointed to parallels between the two fields (e.g., Oppenheim et al., 2010; de Zubicaray et al., 2015; Navarrete et al., 2021), and both fields ostensibly describe modulations within the same conceptual-lexical network, they focus on different aspects of the problem space and remain largely segregated. In the memory literature, accounts of retrieval-induced forgetting address an undifferentiated semantic memory stratum and generally omit consideration of lexical retrieval and selection, though these are clearly implicated in the verbal tasks that experiments employ (Anderson et al., 1994; Jonker et al., 2013; Norman et al., 2007). One influential account explicitly postulates adaptations within this memory stratum as the basis of semantic interference (Norman et al., 2007). Conversely, language production researchers for the most part ascribe

semantic interference to weakened links between conceptual representations and pre-phonological words (*lemmas*), with some researchers proposing that the links are to higher level *lexical concepts* (Belke, 2013; Doring et al., 2022). Regardless of whether conceptual features link to lexical concepts or to lemmas, these language models rely on oversimplified or underspecified conceptual-semantic representations and do not address the possibility of dynamic changes within them that are postulated in some memory accounts. In our view, there is no strong reason to exclude either possibility. Based on current evidence, semantic interference may entail dynamic changes within conceptual representations (e.g., Norman et al., 2007), adaptations to conceptual-lexical links (e.g., Oppenheim et al., 2010), or both. Importantly, in relation to the theme of the special issue on the language-memory interface, we thus do not view memory and language as separate spheres but rather as intrinsic components of a conceptual-linguistic system in which long-term conceptual memory representations are often evoked through language. We now consider aspects of the relevant language production and memory literatures in more detail.

Semantic Interference in Language Production

In language production research, production of words is often studied through timed picture naming tasks that require generation of names from memory. Pictures are assumed to activate conceptual knowledge and corresponding sectors of the lexicon from which the most felicitous, pragmatically fitting name is selected. Picture naming is thus a proxy for the general process of conceptually-driven word retrieval. When speakers produce an individual picture name, they first activate the concept they wish to convey. Semantic concepts, often construed as distributed semantic features (see Kumar, 2021; Lambon-Ralph et al., 2017 for reviews), link to corresponding abstract lexical representations, that is, lemmas or lexical concepts (e.g., Levelt et

al., 1999). As a result, words that share semantic features become coactive as activation spreads throughout the conceptual-lexical network (e.g., Dell & O'Seaghdha, 1992; Levelt et al., 1999; Rapp & Goldrick, 2000). When nontarget words are highly coactive, it can be more difficult for the system to select the optimal word for production, and later access to the activated but not selected competitors is impaired (Howard et al., 2006; Schnur et al., 2009). The *semantic interference effect* in language production is thus the phenomenon in which it takes longer to retrieve and produce words after retrieving and producing related words (e.g., Vitkovitch & Humphries, 1993; Wheeldon & Monsell, 1994; Damian et al., 2001; Howard et al., 2006; Oppenheim et al., 2010; Abdel Rahman & Melinger, 2011; Schnur, 2014; Gordon et al., 2018).

Semantic interference is observed in picture-word procedures (e.g., Schriefers et al., 1990) where printed distractor words are superimposed on pictures, and in cyclic naming, where participants repeatedly name small sets of related or unrelated pictures (e.g., Damian et al., 2001) in rapid succession. Critically, interference is also observed when there are significant lags between related items, such as in the continuous picture naming paradigm (but see Schnur, 2014). In this paradigm, following an initial item familiarization sequence, participants name pictures in a single stream that has been internally structured so that related items are dispersed evenly throughout the sequence (Howard et al., 2006). This means that speakers are generally not aware of the manipulations, that short term effects between related items are limited, and that effects of ordinal position within sequences are plausibly due to long-term adaptive mechanisms rather than to momentary selection difficulty (Howard et al., 2006; Oppenheim et al., 2010). We focus on this paradigm in the current work because it lends itself most naturally to fusion with memory procedures and because the other procedures may involve strategies and control processes that complicate data interpretation (see Belke & Stielow, 2013, for review). In the

continuous naming task, experiments reliably show a linear increase in naming time over related item ordinal positions, such that the time it takes to name a picture increases substantially with each related item previously produced (Howard et al., 2006; Oppenheim et al., 2010; Schnur, 2014). Given that interference increases over related productions, this form of semantic interference is referred to as *cumulative interference.*

What drives this interference? In some accounts, interference is attributed to an increase in the concurrent activation of previously selected lexical concepts at the moment of current target selection (e.g., Roelofs, 2018; Abdel Rahman & Melinger, 2019). To account for the long-term effects of the continuous naming paradigm, the heightened accessibility of recently selected lexical concepts was implemented as a bias term in WEAVER++ model simulations by Roelofs (2018). The bias is temporary and needs to be maintained by frequent reuse within a picture naming procedure (Roelofs, 2018). In contrast, and of particular interest here, adaptive learning accounts hold that word accessibility is shaped by error-driven learning mechanisms (Howard et al., 2006; Oppenheim et al., 2010). According to the earlier account of Howard et al. (2006), cumulative interference is the result of modulation to the mappings between concepts and lemmas. When a word is selected for production, the links between the target's conceptual representation and lemma are strengthened, thus making this word more competitive when a relative is later generated. That is, long-term strengthening of previous targets, rather than bias, is at the root of cumulative interference. Crucially, Oppenheim et al.'s (2010) "Dark Side" model extends the Howard et al. (2006) account by proposing that whereas links to selected words are strengthened, links to activated but unselected words are also weakened during name generation. Specifically, this strikingly simple feed-forward model proposes that the conceptual-lexical links are strengthened for items that are activated and selected for production, while the conceptual-

lexical links of items that were activated but not selected for production are weakened, thereby downregulating the future accessibility of these words. In this view, selection difficulty arises due to previous downregulation of semantic competitors and not only from increased competition from strengthened relatives. Indeed, though strengthened access to previously generated words occurs, Oppenheim et al. show through simulations that it may not play a role in long-term semantic interference (see Oppenheim & Nozari, 2024; Oppenheim, 2024 for additional discussion). Thus a key attribute of this model is that competitive lexical selection is not necessary to capture semantic interference in continuous picture naming (Oppenheim et al., 2010). Given that the work here focuses on the continuous naming paradigm, the role of competitive lexical selection is not crucial in the present context.

All of the language production accounts of semantic interference focus on the accessibility and selection of lexical representations without consideration of processes at the level of conceptual representation (see Oppenheim & Nozari, 2024, for a related point). To our knowledge, no current account considers the possibility that change within the conceptual representations themselves either drives or contributes to interference phenomena. In the next section, we will review an influential account of semantic interference in memory (Norman et al., 2007) in which modulations within a conceptual (semantic memory) stratum drive long-term changes in semantic accessibility.

Retrieval-Induced Forgetting in Semantic Memory

Retrieval-induced forgetting (RIF) is the phenomenon whereby retrieval of material from memory leads to "forgetting," or later retrieval difficulty, for semantically related material (e.g., Anderson et al., 1994). This definition makes the affinity with cumulative semantic interference in language production evident, but also instigates a different framing. The retrieval-induced

forgetting literature disregards language processes, effectively treating them as mere transducers of underlying memory operations. Related to this disregard, the retrieval processes that lead to forgetting are construed as *generation* but the how and what of generation are largely left unspecified (e.g., Norman et al. 2007; Ritvo et al., 2019). Moreover the term forgetting itself may be a misnomer, in that it suggests a categorical process instead of the continuous modulation of accessibility revealed in the language production literature.

These characteristics are exemplified in the primary tool of retrieval-induced forgetting research, the *retrieval practice* paradigm (Anderson et al., 1994). In this design, participants are familiarized with an extensive list of category-exemplar pairs (e.g., FRUIT-apple…. INSTRUMENT-violin…. FRUIT-orange) with multiple items in each category. In a subsequent Generation phase (usually referred to as the *retrieval practice phase* in the memory literature), some items from some of the familiarized categories are generated using category-stem completion cues (e.g., FRUIT-ap____). Generation is repeated several times to increase the rate of successful retrieval. Participants then engage in a distractor task (typically 15-20 minutes) before completing a final memory assessment phase involving all items (typically also using category-stem or category cues). There are two key conditions in this phase[2]. The Activated condition contains new members of the same categories that were generated in the preceding phase (e.g., FRUIT-or_____, when "orange" was not previously cued for the category FRUIT). The Control condition contains members of categories that were not engaged at all during the Generation phase (e.g., INSTRUMENT-vi(olin) when no instruments were invoked during the Generation phase). The *retrieval-induced forgetting effect* is the finding that stem completion is

[2] In the retrieval-induced forgetting literature, the corresponding terms are Rp+ (retrieval practiced) for Generated, Rp- for Activated, and Nrp (no retrieval practice) for the Control condition.

typically less successful in the Activated condition than in the Control condition. A Generated condition (containing items from the Generation phase) is often included as well. This condition reliably shows greater retrieval success than the others (e.g., Anderson et al., 1994; Anderson, 2003; Hulbert et al., 2012). Note that throughout the paper we use transparent, vernacular terms to facilitate broad understanding in place of the procedure-specific acronyms of the retrieval-induced forgetting literature.

Retrieval-induced forgetting (RIF) suggests that prior generation impedes subsequent memory access to categorically related items. We propose that the pattern of impaired access to related material following generation reflects the same underlying process as the semantic interference observed in language production research. A variety of explanations have been proposed to account for interference/forgetting in the memory literature. The early accounts of Anderson and colleagues proposed that Activated items are inhibited during the Generation phase making them less accessible than controls at later testing, (Anderson et al., 1994; Anderson & Spellman, 1995). The long-term mechanism of this inhibition was left underspecified. Other accounts attribute retrieval-induced forgetting to a blocking process in which previously generated items preclude access to ungenerated competitors from the same category (see Murayama et al., 2014 for an extensive review). According to blocking accounts, encountering category cues used in the Generation phase during the final memory assessment activates the Generation phase context, thereby promoting access to previously Generated items at the expense of related Activated items that are not linked to that context (Jonker et al., 2013; Jonker et al., 2015). However, contrary to this account, RIF has been replicated across a variety of tests specifically designed to limit the influence of context, including variations in which new cue words without any relation to the practiced category cues are used to elicit retrieval during

the final assessment phase (e.g., Anderson, 2003; Hulbert et al., 2012; Hanczakowski & Mazzoni, 2013). We suggest that while context certainly plays a role in some scenarios (see Norman et al., 2007 and Murayama et al., 2014, for review), the blocking accounts do not explain the full range of semantic interference findings.

One other account of retrieval induced forgetting, the computationally implemented adaptive learning account of Norman et al. (2007; see also Norman et al., 2006), is of particular interest from the point of view of rapprochement with the language production literature. This account is partly a successor to the earlier Anderson et al. inhibition account but implemented through specific neurally-inspired mechanisms. In the model, stem-cue retrieval is implemented as pattern completion, and adaptive learning processes act on the connectivity between microfeatures within conceptual representations. When a particular memory representation is retrieved amidst coactivated competitors, an algorithm identifies weak aspects of the target representation and overly active aspects of semantic competitors. A learning mechanism then strengthens the connections of the weakly activated target features and weakens the connections to overactive features within competing representations, thereby making them more and less accessible, respectively, in future use (Norman et al., 2007). Thus the incremental adjustment of access to competing items matches the downregulation proposed by Oppenheim et al. (2010) to occur in language production, albeit with a different proposed locus and implementation.

Bridging the Literatures

Thus far, we have argued that retrieval-induced forgetting and cumulative semantic interference are both situated in an interconnected conceptual-lexical network, that both may be attributed to adaptive learning mechanisms in the network (e.g., Hughes & Schnur, 2016; Oppenheim et al., 2010; Navarrete et al., 2010; Hulbert et al., 2012; Norman et al., 2007), and

that they may indeed be the same phenomenon (Navarrete et al., 2021; Jeye et al., 2021, but see de Zubicaray et al., 2015). So why has there been so little integration or direct comparison of findings in the two fields? Contributing factors may include the use of different dependent measures and very different experimental designs and procedures. Moreover, as discussed, each literature proposes a different locus of interference, and there is a differential consideration of episodic versus semantic memory processes. We now address each of these issues in turn.

Methodological Considerations

First, the underlying commonalities may be masked by the different research practices of memory and language production researchers. Language production researchers are thoroughly entrenched in picture-naming procedures, whereas the RIF literature is dominated by the valuable but restrictive retrieval practice paradigm, even to the point of adopting procedure-specific labels that impede broader thinking. The most important element is the use of different dependent measures, specifically the exclusive use of continuous latency measures in language studies and of aggregate retrieval success measures in memory experiments. Indeed it appears that the siloing of these practices occurred despite evidence of their common ground. A seminal study of semantic interference measured both latency and aggregate retrieval success for category-stem prompts (Brown, 1981). Brown observed both longer latencies and higher probability of retrieval failure over successive probes within categories. The study was cited both in initial studies of retrieval-induced forgetting (e.g., Anderson et al., 1994) and in studies of interference in word production (e.g., Kroll & Stewart, 1994; Howard et al., 2006). It is notable that, since then, retrieval-induced forgetting studies have almost exclusively relied on aggregate retrieval success as a dependent measure. In doing so, they have lost the ability to examine how semantic interference unfolds within generative and memory assessment phases of experiments,

as well as the sensitivity of latency measures to modulation of accessibility among retrievable items in different conditions. On the other side, although they do routinely log naming errors, including omissions, language production studies rarely consider memory failures. One reason for this is that omissions and other errors are infrequent in picture naming. In any case, unification of memory and language production contributions may require a return to Brown's (1981) early diligence in using both latency and memory measures.

Related to the previous issue, the two fields also use different ways of eliciting generation, picture naming (language production) and category-stem cueing (memory). We suggest that there may be little fundamental difference in the generation requirements of category-stem cued retrieval and picture naming, though. There is some evidence to the contrary. Specifically, de Zubicaray et al. (2015) failed to find activation in brain areas typically associated with the Generation phase of retrieval-induced forgetting (i.e., hippocampus, right IFG, and ACC; see Kuhl et al., 2007) during continuous picture naming, and they concluded that the two phenomena are neurally distinct. We suggest that these differences are due to superficial modality differences rather than indicating these effects arise by wholly distinct mechanisms. We also note that the lack of activation in the ACC is inconsistent with other picture naming studies that found significant activity in the same regions (e.g., Indefrey & Levelt, 2004; Gauvin et al. 2016; Llorens et al., 2016). Overall, we retain our position that picture naming shares some key retrieval processes with category-cued stem completion.

Another methodological impediment to integration is that the study of cumulative semantic interference in language production has focused on the unfolding impact on latencies within a single continuous sequence, while retrieval-induced forgetting is studied using a multiphase design in which success in the final phase reflects learning in a prior phase. Each of

these approaches has distinct benefits and limitations. In continuous picture naming, the primary focus is on examining how each retrieval instance dynamically impacts access to categorical relatives later in the same sequence. The Generation phase in the retrieval practice paradigm often follows a quite similar design to the continuous naming task in that it requires iterative conceptual-lexical retrieval of interspersed category members within a single sequence. Given that adaptive learning accounts (see prior discussion) assume that downregulation of competitors occurs during the Generation phase, it is puzzling that the field has focused on measuring the retrieval of related items in the final assessment phase, rather than also investigating the internal dynamics of the Generation phase itself (see Kuhl et al., 2007, for an exception). The present work addresses this crucial weakness in the memory research.

At the same time, our research addresses a significant weakness of language production studies by adopting a *retrieval-induced forgetting* design. The final assessment phase of this design compares the effect of prior related retrieval to a true baseline (control) condition. Continuous picture naming has no such baseline measure, leaving some ambiguity as to whether the changes are exclusively due to semantic interference. Thus, each of these approaches has benefits and limitations, and combining them may provide a fruitful way to investigate the commonalities underlying the findings of the two subfields.

Assumed Locus of Interference

A key issue that separates the literatures is the presumed location of interference in long-term semantic memory versus in conceptual-lexical links. This issue is complex as there is no unanimity on this question in either literature. We have argued above that, in both literatures, adaptive learning accounts can best explain the existing findings. Therefore, we suggest that the issue of locus can be reduced to the contrasting assumptions of the two influential computational

models of Norman et al (2007) and Oppenheim et al (2010). A more detailed consideration of these two models illuminates both the possible benefits and challenges of bringing them into correspondence. In Norman et al. (2007), adaptations are proposed to operate on intra-conceptual configurations of features, whereas in the model proposed by Oppenheim et al. (2010), adaptations modulate the strength of conceptual-lexical links. We suggest here that both literatures are technically compatible with interference arising from either of these loci. For example, one could argue that the Norman et al. (2007) model implicitly incorporates lexico-conceptual representations in the hidden layers that bind collections of semantic features. Therefore, bindings between these wholistic representations and features could potentially vary with generative activity. Likewise, the Oppenheim et al. (2010) model could be modified to allow lateral, dynamic changes in conceptual ensembles as well as changes in conceptual-lexical bindings. Pending new evidence on this matter, semantic interference may be attributable to intra-conceptual change, to change in conceptual-lexical connections, or some combination of both.

Lastly, whereas semantic interference in language production is studied as a semantic phenomenon, retrieval-induced forgetting accounts often include episodic memory processes. This issue is exemplified by the previously discussed contextual blocking accounts, which have posited that "forgetting" results from using cues that are episodically bound to the Generation phase context (e.g., Jonker et al., 2012). However, new cues without any intrinsic relatedness to the target (i.e. purely episodic cues) do not produce interference (e.g., Perfect et al., 2004). This suggests that RIF (and in turn, semantic interference in language production) is not a purely episodic phenomenon. In any case, we do not focus on the semantic-episodic distinction in the current work, a position that is in line with modern critiques of over-segregated

conceptualizations of episodic and semantic memory (Yee et al., 2018; see also McRae et al., 2021).

In sum, the bridging of these literatures and their perspectives is long overdue. We suggest that aligning both the theoretical claims and empirical evidence in the cumulative interference and retrieval-induced forgetting literatures will deepen understanding of retrieval-based changes in both conceptual memory and word accessibility and clarify the division of labor between processes in conceptual memory substrates and in lexical pathways. In the current study, we seek to combine the strengths of both language production and memory perspectives in order to overcome their respective weaknesses, thereby paving the way for future integrative work.

Present Experiment

In light of these considerations, we designed an experiment that brings the memory and language production literatures into dialogue. Although there are many ways in which integration of these two literatures could be implemented, in this initial investigation we primarily seek to make the case that cumulative interference and retrieval-induced forgetting (RIF) entail the same or similar learning mechanisms acting on the same semantic representations. Specifically, we measured latencies in a structured retrieval practice design to investigate if cumulative interference, as is typically found in the language production literature, occurs similarly in a category-stem cue Generation procedure. Critically, we also assessed if this generative activity impaired later accessibility of related picture names relative to controls, implementing a retrieval-induced forgetting design in a continuous picture naming procedure.

The present experiment follows the four-part structure of a standard retrieval-induced forgetting. The design entails an initial familiarization procedure (standard in both literatures), a

Generation Phase using category-cued stem-completion, a filled retention interval, and a final Picture Naming Phase. In the initial familiarization procedure, participants were presented with each picture paired with its category and name, which both aids in instantiating the specific category-target combination for the Generation Phase and reduces errors associated with "exuberant responding" in the later Picture Naming Phase (Ferreira et al., 2008). In the Generation Phase, fidelity was maintained to the repeated category-stem completion procedure of the retrieval-induced forgetting literature, however; an internal quartile structure was implemented in which related items are distributed equally across the sequence. Note that this is a much more highly controlled presentation than typically used in RIF studies. By measuring both generation latencies and errors, we sought to demonstrate that cumulative semantic interference occurs in the same way whether generation is cued by category-stem prompts or by pictures. The prompts were presented in three passes to ensure adequate exposure, although past work has suggested that adaptive learning processes may primarily occur in the first pass (Kuhl et al., 2007). We thus predicted cumulative interference across related item generation, primarily in the first pass through the materials. An earlier study with a similar design used single letter cues (i.e., INSECTS – b___) during this phase, but retrieval success was lower than desirable (see Hambric & O'Séaghdha, 2022). The current experiment thus used two-letter stem cues. The Generation Phase was followed by a 15-minute retention interval in which participants completed a medium-level sudoku puzzle. Participants then completed the final Picture Naming Phase, which followed the typical design of a continuous picture naming task and again assessed name generation latencies. In this final phase, we only included the critical Activated and Control conditions. This was partly because the positive effect of prior generation is uncontroversial and highly reliable. More importantly, given that cumulative interference unfolds

across categorically related items, and that Generated and Activated items are drawn from the same categories, we chose to implement a balanced design comprising only the never-generated Activated and Control conditions. This mitigates the possibility of contamination from previously generated items and provides a clean test of the influence of past related generative activity. Critically, we predicted that, on aggregate, it would take longer to retrieve and produce picture names in the Activated condition relative to the control condition. We also expected typical cumulative interference in both conditions.

Method

Participants and Power Considerations

The cross-paradigm nature of the present study made estimation of predicted effect size and required power difficult. Rather than conducting a power analysis, we estimated the appropriate power using the guidelines proposed by Brysbaert & Stevens (2018). According to their recommendations, a reaction time experiment with repeated measures should have a minimum of 1,600 observations per condition. Given that there were 20 target trials in each condition of the critical picture naming phase, 96 participants were recruited from Lehigh University in return for either $8 US (N=13) or class credit (N=83) in an introductory psychology course, resulting in up to 1920 measures per condition.

Materials and Apparatus

Ten groups of eight taxonomically related items (80) were selected from the Bank of Standardized Stimuli (Brodeur et al., 2010; Brodeur et al., 2014). In addition, five unrelated fillers were presented at the beginning and end of the Generation phase (see Design) to mitigate primacy and recency effects. Ten additional fillers were presented as task practice at the beginning of the continuous Picture Naming Phase to reduce data loss on experimental trials.

The relatedness of items in each taxonomic group was established using normative data from the Bank of Standardized Stimuli (Brodeur et al., 2010; Brodeur et al., 2014) and additional frequency data were acquired from the LexOPS data base to ensure selected items were as equivalent as possible (Taylor et al., 2020). Both average name agreement (87%) and average category agreement (94%) were high and always exceeded 60%. The complete list of materials and selection criteria can be found on OSF (https://doi.org/10.17605/OSF.IO/UASFM). Pictures were presented centrally and sized to approximately 4 in x 4 in (Brodeur et al., 2014). Text was presented in 14-point Corsolas font. The filler task was a printed medium level sudoku puzzle.

The experiment was programmed using E-Prime 3.0 and was conducted using a Dell OptiPlex 7020 computer with a 1908FPt 75 DPI monitor with a refresh rate of 80 Hz. Participants were seated approximately 16 inches from the screen. Voice onset times were recorded using a Psychology Software Tools 200A SR box interfaced to an ATR20 Audio-Technica microphone, situated approximatelty12 inches away from the participant, and audio for the entire session was recorded using a SONY ICD-PX720 recorder.

Design

The experiment comprised four sub-procedures, including an initial familiarization procedure, a Generation Phase, a filler task, and a final Picture Naming Phase. The two critical phases comprised two distinct but linked designs (see below). Assignment of categories between the Generation Phase and the Control condition was balanced across two experiment versions, and assignment of items to Generated vs. ungenerated (Activated) status within each version was further counterbalanced over two sub-versions. To equate the number of items in the Activated and Control conditions, only half of the items in the Control condition were presented, and the half presented was counterbalanced in the subversions.

Generation Phase

This phase comprised the "retrieval practice" phase typically implemented in retrieval - induced forgetting experiments (e.g., Anderson et al., 1994). Participants underwent category-stem completion retrieval for half (4) of the items from half (5) of the categories. One item from each category was presented in each of four quartiles, thus distributing related items evenly. The order of quartiles was balanced across participants via a Latin Square, and items were randomly presented within quartiles. Following standard practice, this sequence was repeated three times, each Repetition implementing a new ordering of quartiles and items and with no immediate repetition of quartiles across Repetitions. Filler items were presented only once, before the first Repetition and at the end of the third. In this phase, the key variables were the within-subject factors Ordinal Position (1-4) and Repetition (1-3).

Continuous Picture Naming Phase

In this phase, pictures corresponding to items in the Activated and Control conditions (see above) were presented in a continuous stream. Prior to the experimental trials, 10 unrelated filler pictures were presented to reduce data loss associated with task orientation. As in the Generation phase, one item from each Activated and Control category was randomly assigned to each quartile. The order of presentation within each quartile was randomized, and the order of quartiles was counterbalanced across experiment versions. Because immediate repetitions from the same category were not allowed, there was a minimum lag of 2 and a maximum lag of 19 between members of the same category. Thus, there were two within-subject factors: Memory Condition (Activated versus Control) and Ordinal Position (1-4).

Procedure

The experiment comprised four separate procedures (see Figure 1).

Familiarization

Following standard practice in both the memory and language production literatures, participants were first introduced to the materials. They were told that they would be naming a series of everyday objects and that they would be using the information in subsequent tasks. All items used in later phases, including fillers, were presented as pictures with their category and name in a randomized sequence. Presenting the names with the pictures eliminates the need for active lexical retrieval but makes the designated names (as well as the category-name combinations) available for the experimental phases. Thus, both the category-exemplar pairs and corresponding pictures were introduced in a single pass.

On each trial, a fixation cross appeared for 200 ms, followed by the presentation of a picture with the category-name combination (e.g., INSTRUMENTS – violin) below it for 1500 ms. To ensure that the information was registered, participants read each category and picture name aloud. The experimenter provided feedback on standard pronunciation on the few occasions where it was necessary. No data were collected.

Generation Phase: Category-stem Cues

In this phase, participants were instructed (with examples) that they would be presented with category-stem cues for some of the familiarized items on each trial and that they should try to retrieve the word matching the cue as quickly and accurately as possible. They were told that each category-stem cue would appear multiple times and that they were to remain silent if they did not recall the word. The stems were always the unique first two letters of the target name. Each category-stem cue was assigned to a quartile in a continuous sequence, and the whole sequence (with new randomization) was repeated three times (see Generation Phase Design). Five fillers were presented at the beginning and at the end of the phase to alleviate possible

primacy and recency effects. On each trial, a fixation cross appeared for 200 ms, followed by the category name and the two-letter stem of the target (e.g., INSTRUMENTS – vi____). The display lasted for 8 seconds or until a naming response was registered. In order to encourage effortful retrieval across repetitions, no feedback was provided during the Generation phase. The next trial began 1000 ms after the conclusion of the previous one.

Filler Task

Participants worked on a printed medium difficulty level sudoku puzzle for 15 minutes. They were instructed to try to complete the puzzle to the best of their ability, but that there would be no formal assessment of their sudoku performance. The attention-demanding, numerically oriented sudoku task was selected to prevent participants from engaging with/rehearsing experimental materials during the interval.

Final Assessment Phase: Continuous Picture Naming

Participants named the target pictures in one continuous sequence internally segmented into quartiles (see Design). Ten unrelated filler pictures preceded the experimental trials. On each trial, a fixation cross was presented for 200 ms followed by the printed category (e.g., INSTRUMENTS) of the upcoming picture for 750 ms. Category labels are not usual in picture naming procedures but were used here for consistency with the Generation phase. The target picture (without label) was then presented for up to 1500 ms or until a naming response was registered. A tone sounded and a “too slow” message appeared for 200 ms if the time limit was exceeded. Another trial began 1000 ms after the previous one. Following the completion of this phase, participants were thanked and received an educational debriefing.

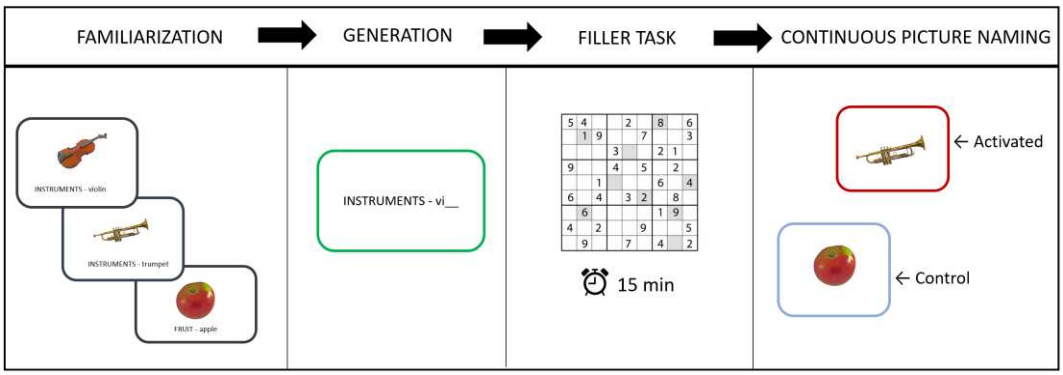

Figure 1. Schematic of the four-part experimental procedure.

Results

Audio recordings of each session were coded off-line by the first author and trained research assistants. Trials in which an environmental sound set off the voice key and trials in which the reaction time was less than 250 ms were coded as invalid and excluded from all analyses. In both the Generation and Continuous Picture Naming phases, trials in which a participant used an incorrect or incomplete name, responded dysfluently, or did not respond, were coded as salient naming errors and excluded from latency analyses. Both latencies and salient errors are analyzed.

Separate linear mixed model analyses were conducted in R version 4.0.3 using the *afex* package (Singmann & Kellen, 2019) for the Generation and Picture Naming Phases. Sum-zero contrasts were set for the relevant categorical variables and F-tests for the fixed effects were conducted with Satterthwaite approximations applied to estimate the degrees of freedom. There was no meaningful effect of the counterbalancing factor and it was therefore excluded from analyses.

Generation Phase

Latency Analysis

Descriptively, generation time decreased across Repetitions ($Mean_{R1}$ = 1441, SE = 38; $Mean_{R2}$ = 1242, SE=38; $Mean_{R3}$ = 1110, SE=38). More importantly, a 182 ms increase in generation time across ordinal positions was observed in the first Repetition. There was little effect of Ordinal Position in subsequent Repetitions (see Figure 2).

The maximally converging linear mixed model for latencies included the fixed main effects of Ordinal Position, Repetition, and their interaction, as well as random intercepts for both subjects and items. There was a main effect of Repetition, in which generation times decreased more than 300 ms over Repetitions, F (2,3988) = 113.20, p <.001. The main effect of Ordinal Position was also significant *(*F (3,3997) = 4.51, p =.004): Generation times increased with each newly retrieved category member. Importantly, the effect of Ordinal Position was qualified by a significant interaction between Repetition and Ordinal Position (F (6,4024)=6.50, p <.001), which reflects the concentration of cumulative interference in the first Repetition (see Figure 2). The concentration of effects within the first repetition replicates previous behavioral evidence in the RIF literature (Kuhl et al., 2007). It remains possible that further accumulation of interference was masked by rapid responding in the second and third repetitions. Overall, these data indicate that cumulative interference arises in category-stem completion in the same way as in previous picture naming studies, and that it may not accumulate further in repeated passes through materials.

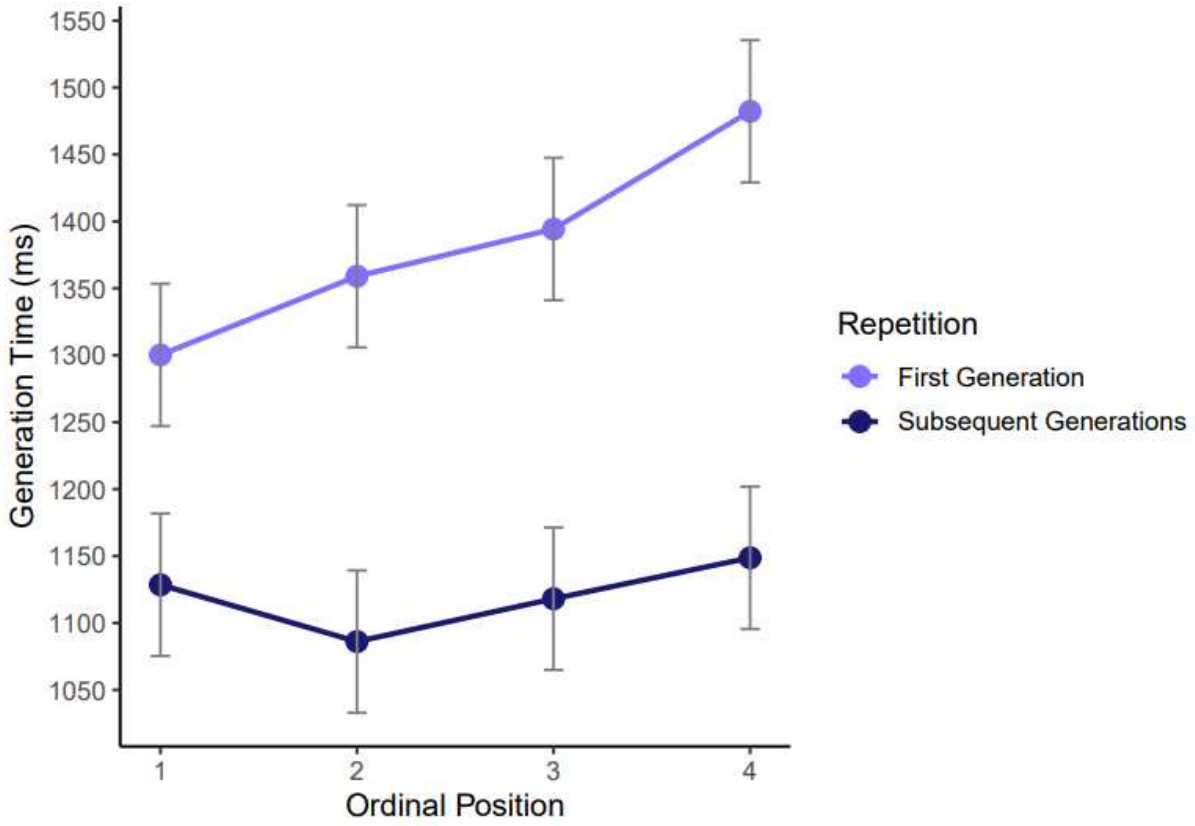

Figure 2. Cumulative interference in production time for targets in the Generation phase. Subsequent Generations are aggregated over second and third repetitions.

Error Analysis

The total error rate in this phase was 19%, which is slightly lower than the retrieval failure rate found in the RIF literature. Descriptively, retrieval errors decreased only slightly with Repetitions (Mean $_{R1}$=22%, Mean $_{R2}$=19%, Mean $_{R3}$=17%). In the first Repetition, the error rate slightly increased across Ordinal Positions, Mean $_{Q1}$=20%, Mean $_{Q2}$=22%, Mean $_{Q3}$=20%, Mean $_{Q4}$=25%. Naming errors comprised 91% of all errors, and of these errors, only 249 were commission errors, such as semantic substitutions (e.g., "ha(ndkerchief)" for "ha(t)") while 964 were omissions in which the participant failed to give any response at all within the eight second

response window. These omission errors most closely correspond to the retrieval failures reported in the RIF literature. It is notable that, both here and in the RIF literature more generally, retrieval failures are substantial despite the familiarization procedure.

The error analysis included salient naming errors as explained earlier. A logistic linear mixed model analysis was conducted on the error data. Due to error sparsity, the maximal model included only the fixed effect of Repetition and random intercepts for participants and items. We were not able to statistically assess the effect of Ordinal Position. There was a main effect of Repetition (χ^2=15.62, p =.001) such that errors decreased across Repetitions. This reflects that participants occasionally generated items in later repetitions that were not retrieved previously. Thus, although adaptive learning processes may primarily operate in the first Repetition, subsequent repetitions may still be somewhat useful in eliciting additional retrievals.

Continuous Picture Naming Phase

Latency Analysis

As predicted, picture naming time in the Activated condition (Mean =792, SE =13) was longer than in the Control condition (Mean=769 , SE=13), a retrieval-induced semantic interference effect. Naming times also increased over the first three Ordinal Positions (see Figure 3), showing new interference within the Picture Naming phase and convergence of latencies in the two conditions over Ordinal Positions.

The maximal linear model included fixed main effects of Memory Condition and Ordinal Position as well as their interaction, and random intercepts for both subjects and items. Critically, the 23 ms main effect of Memory Condition, F (1,3011) = 9.66, p = .002, a retrieval-induced semantic interference effect, was significant. The increased interference over quartiles was also significant (F (3,3014) =15.88, p < .001), indicating new cumulative interference over Ordinal

Positions in both conditions. In addition, the interaction between Memory Condition and Ordinal Positions was marginally significant (F (3,3009) =2.56, p = .053), suggesting that the steeper accrual of interference in the control condition is meaningful. Planned comparisons show that the effect of Memory Condition was significant only in the first (z = 3.23, p < .001) and second (z = 2.31, p = .02) Ordinal Positions. In both conditions, and in contrast to the Generation phase, accumulation of interference converged in the third Ordinal Position and was absent in the fourth. Moreover, there was no difference between the conditions in the fourth Ordinal Position. The important implication of this finding is that retrieval-induced interference from the Generation Phase can be stronger early on in subsequent processing (here, continuous picture naming) and may even be completely absent as new interference unfolds.

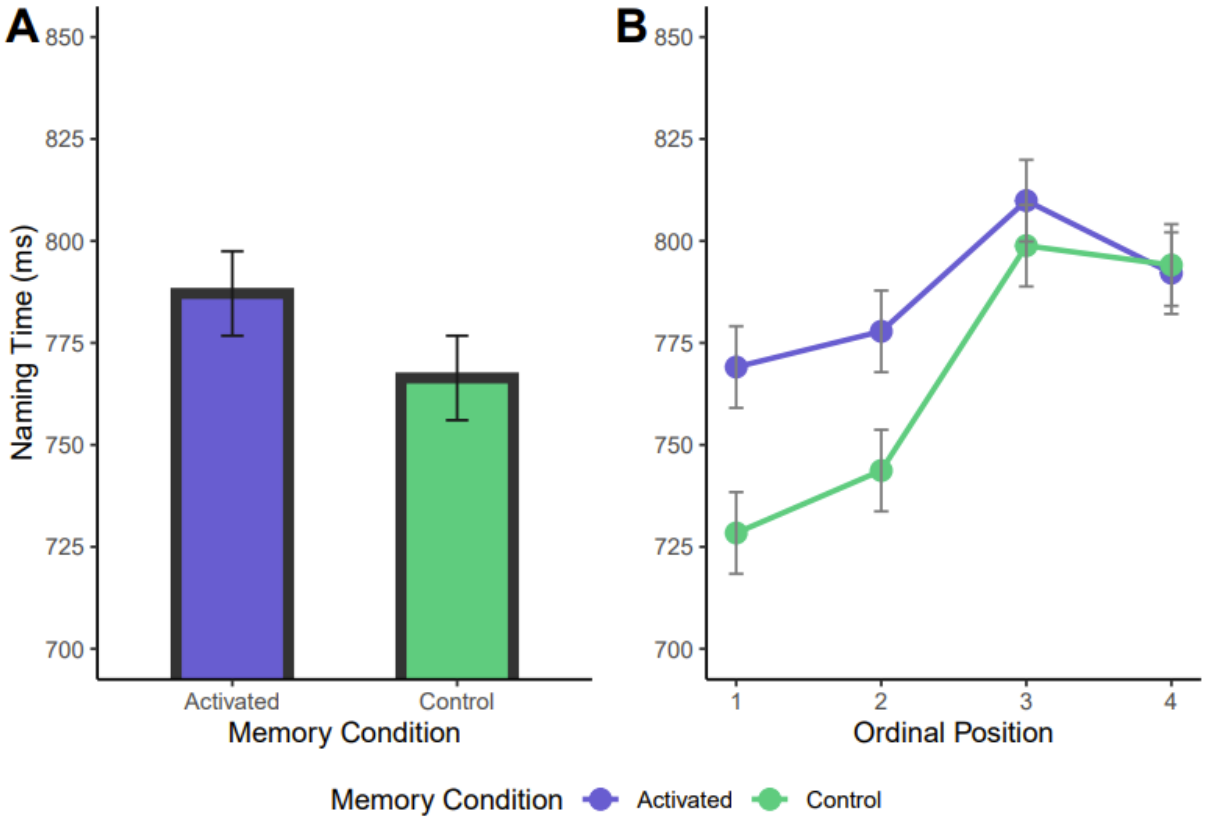

Figure 3. Picture Naming Time as a Function of Memory Condition. A) Significantly greater picture naming RTs for previously Activated categories relative to unactivated Controls. B) Cumulative interference in experimental and control conditions converges over Ordinal Positions.

Error Analysis

The overall error rate in this phase was 12%. Naming errors comprised 86% of all errors, and of these errors, 205 were commission errors, and 262 were omission errors. The number of errors was similar across Memory Conditions, Activated= 159, Control = 150. A logistic linear mixed model analysis was conducted on the target naming errors as in the Generation phase. The final model included the fixed factors, Memory Condition and Ordinal Position, their interaction,

and random intercepts for subjects and items. The effects of Memory Condition (χ^2=0.66, p >.05), Ordinal Position (χ^2=2.00, p >.05), and their interaction (χ^2=3.39, p >.05) were not significant. Thus, whereas we observed a RIF pattern in naming latencies, we did not observe any effects in errors. Picture naming errors in this study may thus be mostly due to considerations other than semantic interference.

Discussion

This research is part of a larger effort to bring independent but parallel language and memory accounts of retrieval-based long-term semantic interference into alignment. Separate cumulative semantic interference (language production) and retrieval-induced forgetting (memory) literatures both investigate decrements in later accessibility of activated but unselected concepts or words. Influential accounts within each literature propose that adaptive incremental learning processes are at the root of these decrements (Oppenheim et al., 2010; Howard et al., 2006; Norman et al., 2007), but synthesis of these complementary perspectives has yet to occur. The review of the respective literatures highlighted the strengths and limitations of current memory and language production approaches to semantic interference, and the experiment illustrated the value of an integrative approach. The findings showed lasting semantic interference in a continuous picture naming procedure following earlier related generative activity. The ways that semantic interference accrued over time within both stem-completion (Generation) and picture naming (Assessment) phases provided additional insights. We conclude that there is no difference in the underlying basis of *retrieval-induced forgetting* and *cumulative semantic interference,* and therefore propose that the literatures be integrated under the rubric *retrieval-induced semantic interference.*

Key Findings

We now consider key findings in more detail. The experiment adopted a retrieval practice design from the retrieval-induced forgetting literature but employed latency measures to provide continuous assessment of semantic interference in both the Generation (category-cued stem completion) and Assessment (picture naming) phases of the procedure. The design provided a rigorous test of long-term interference relative to baseline and, by changing tasks between the crucial phases, showed that interference is a general process. The Generation phase, harking back to pioneering work of Brown (1981), measured latencies as well as errors in a structured category-cued stem completion task. The presentation sequence was structured such that one member of each category occurred in each of four quartiles. We observed cumulative interference in latencies only in the first of three presentations of the sequence. Analysis of this phase thus provides insight into the emergence of interference in a typical memory research procedure and suggests, in agreement with Kuhl et al., (2007), that the standard practice of eliciting generation multiple times may have limited value.

In the final picture naming phase, it took longer to name pictures corresponding to new items from previously used categories relative to controls. That is, the findings showed a retrieval-induced forgetting (RIF) pattern in picture naming latencies despite the change of format between the Generation and Assessment phases. The use of full counterbalancing between conditions, and over ordinal positions within them, adds confidence to this finding. The effect survived a 15 minute retention interval, providing important evidence for the temporal durability proposed in both memory and language accounts that incorporate incremental learning (Norman et al., 2007; Oppenheim et al., 2010). This is solid evidence of long-term semantic interference relative to a true baseline – which we have noted is absent in most language

production studies of semantic interference in continuous picture naming. In addition to the interference carried over from the Generation phase, additional interference accrued over ordinal positions in both the Activated and Control conditions of this phase, with a somewhat steeper accumulation observed in the Control condition. Planned comparisons showed that the difference between the conditions was significant only in the first half of picture naming. Although this finding was not predicted, it underlines the value of examining cumulative interference rather than only using aggregate measures of successful retrieval. Additional within-task experimentation will be needed to establish whether the accumulation of interference is stronger earlier than later in a sequence of retrievals, or whether another explanation is required.

The durability of semantic interference across tasks in the presented experiment provides novel evidence for cue-independence, a central tenet of long-term adaptation accounts of retrieval-induced forgetting (e.g., Anderson, 2003; Hulbert et al., 2012; Camp et al., 2007; Perfect et al., 2004). The cue-independence assumption states that retrieval-induced forgetting is independent of the particular cues used to elicit retrieval and so involves change within semantic memory (Anderson, 2003). The assumption has been tested by using different retrieval cues during initial and later retrievals (e.g., Hulbert et al., 2012). However, finding truly independent cues can be difficult, and even when this problem is solved participants may nevertheless use the originally assigned categories covertly (covert cueing hypothesis, see Jonker et al., 2012). In the present study, we used pictures as independent cues in the Assessment phase, and still observed a retrieval-induced forgetting effect in the picture naming latencies, supporting cue independence.

Extensions of Present Study

The study presented here used one particular design that combined elements of memory and language production methodologies, but of course many other variations are possible. First,

in the present study we implemented the standard repeated category-stem cueing procedure during the Generation phase and used picture naming in the Assessment phase. While the switch from category-stem cue to picture naming highlights the robustness of semantic interference, it would be interesting to see if a similar pattern of results would be obtained if the tasks were flipped, such that the Generation phase entailed picture naming and the Assessment comprised category-stem cued retrieval. This would make it possible to assess aggregate memory measures as well as continuous retrieval latencies, providing more direct comparison to findings in the retrieval-induced forgetting literature. Both phases could use category-cued stem completion, as is done in the RIF literature (sometimes with minor changes between phases), or both phases could use picture naming. Each of these variations could provide additional insights.

Second, our findings call for further investigation of the value of repetitions in the Generation phase. Repeated generation is typical in the retrieval practice paradigm, but the present results suggest that adaptive learning processes are primarily visible in the first generation of the items. Thus, it is not clear whether repetitions are necessary to induce robust interference for related items, or if they merely serve as additional opportunities to retrieve items that were not retrieved in the initial pass. Some work in the language production literature has found that full lexical retrieval is not required to observe cumulative interference, that is, downregulation of coactivated items may occur even if the target is not generated (Navarrete et al., 2021), making the value of repeated retrievals questionable. Varying the repetitions is easy to implement and will help inform under what conditions adaptive learning operates.

Lastly, we chose not to repeat items from the Generation phase in the Assessment phase for reasons discussed earlier. It would be valuable to assess whether including a Generated condition affects the Activated condition, and especially the accumulation of interference over

Ordinal Positions. Specifically, we reasoned that naming previously generated and strengthened items intermittently within the sequence could disrupt the linear accumulation of interference in the Activated condition. While this is at odds with the finding that repeating a single item did not disrupt the overall linear trajectory of cumulative interference in Oppenheim et al.'s (2010) Simulation 2, whether the same is true for an equal number of repeated and ungenerated items is far less certain and warrants further investigation. In sum, it would be useful to know both whether inclusion of the Generated condition affects the strength of retrieval induced semantic interference, how this plays out over time, and whether the Generated condition itself shows new interference in a later phase.

Methodological Considerations

We highlight four concrete methodological recommendations based on lessons learned from the present study. One, impaired access to Activated items relative to Control was observed in latency data. In addition, latencies reveal changes in accessibility that aggregate retrieval measures that are typically reported in the memory literature do not. Thus, we strongly recommend the use of latency measures in the assessment of semantic interference. Two, we recommend that future work in retrieval-induced forgetting use latencies to assess the interference in *both* the Generation and Assessment phases within the retrieval practice paradigm. Specifically, further investigation into the internal dynamics of the Generation phase is needed to understand exactly how adaptive learning unfolds over time, and under what conditions. Three, the design of the retrieval practice paradigm provides a baseline for assessing sustained interference that has been lacking in the language production literature. The lack of a true baseline is a weakness of the continuous picture naming paradigm, and implementation of a multiphase design such as we use here addresses this issue. Future cumulative interference

studies should incorporate true baselines. Fourth, the present work differentiated between error types in both the Generation and Picture Naming phases. In the memory literature, errors are viewed as the converse of successful retrieval, and they are generally not analyzed further. Moreover, some responses that may be recorded as erroneous in the language production literature, such as disfluent responses, are not counted as errors in the memory literature. The language production literature has a long history of using the *type* of error to further elucidate underlying processes. For example, complete generation failures are termed omission errors, and other types of errors that entail dysfluent or inaccurate responses are termed commission errors. Such a nuanced approach to the analysis of errors, and how proclivity differs across tasks, might likewise provide insight in studies of memory retrieval.

Theoretical Considerations

Integration across literatures must happen at a theoretical level in addition to incorporating useful aspects of respective methodologies. Specifically, comparison of theoretical assumptions across literatures may inform concurrent debates and serve as a catalyst for integration. One example of this can be seen in how both fields conceptualize the relative contribution of the strengthening of selected targets and the downregulation of coactivated competitors, the so called "occlusion versus inhibition" debate. As discussed previously, within the field of retrieval-induced forgetting, researchers posit that retrieval-induced forgetting may be due to strengthened Generated items "occluding" retrieval of related items associated with the same cue, or to mechanisms that affect the representations of semantically competitive Activated items during the Generation phase (see Anderson, 2020, for review). Critically, this is analogous to the debates regarding the role of strengthening and downregulation in the continuous naming task (Howard et al., 2006; Schnur et al., 2009; Oppenheim et al., 2010). Oppenheim et al. (2010)

explicitly referenced the debate within the RIF literature when attempting to disentangle the roles of these two complementary forces. In Simulation 5, Oppenheim et al. isolated the respective contributions of target strengthening and competitor weakening in cumulative interference by manipulating the inclusion of the strengthening and downregulation components of the incremental learning mechanism. In the simulation, Oppenheim et al. (2010) found that, in line with many retrieval-induced forgetting results, suppression of competitors, rather than strengthened access to past targets, was the primary driving force behind cumulative interference. Thus, support across domains strengthens the theoretical claim that it is the downregulation aspect of adaptive learning that drives hindered access to semantic competitors, and future insight might be drawn by making other such cross-field comparisons.

In addition to the issue of cue independence discussed earlier, several other theoretical assumptions formalized by Anderson and colleagues may be fruitful areas of theoretical alignment and testing. The assumption of *retrieval specificity* states that explicit retrieval (rather than mere exposure) is necessary for semantic interference. This is evidenced by the absence of interference when items are presented (but not generated) prior to the assessment phase (e.g., Ciranni & Shimamura, 1999; see Murayama et al., 2014 for review). The same assumption is made throughout the language production literature, and presumed by Oppenheim et al. (2010), but has not undergone much explicit investigation. Preliminary work within our own lab confirms that cumulative interference is not found when reading semantically related words aloud rather than generating the names from pictures (O'Séaghdha et al., in prep), but further work is needed on this topic.

The assumption of *interference dependence* states that the degree of observed forgetting is dependent on the degree of interference during the Generation phase (Anderson, 2003).

Corresponding findings within language production are mixed. For example, Rose et al. (2019) found cumulative interference for related items with high feature overlap (e.g., *chimpanzee, orangutan*) but *not* for those sharing only a broad category membership (*orangutan, donkey*). However, this finding is at odds with the observation of cumulative interference for thematic relations (without any feature overlap, e.g., *pacifier* and *baby,* see Rose et al., 2019), so clearly more research is needed to clarify these contradictory findings. Lastly, the assumption of *temporal insensitivity* explicitly proposed by Oppenheim et al. (2010) and implicitly assumed by Anderson et al. and Norman et al. (2007) is severely under researched. According to Oppenheim et al. (2010), cumulative semantic interference is insensitive to time, such that it only dissipates with relevant production experience. The current evidence for this assumption is also mixed. While some work suggests that interference does dissipate across extensive lags of unrelated items (Schnur, 2014), the present study showed that interference persisted across a 15-minute retention interval. The longevity of semantic interference in memory has also been subject to debate with mixed results, with some work suggesting that forgetting vanishes after 24-hours (MacLeod & McRae, 2001) and other studies showing that it is observable even after a one-week delay (Storm et al., 2012; Tandoh & Naja, 2007). Clearly, there is a strong overlap of theoretical interests across literatures, and we expect that these specific issues and others would be better addressed in a unified framework.

A Unified Conceptual-Lexical Approach

The initial integrative work reported here provides clear evidence of common ground between memory and language production approaches to semantic interference, but also leaves questions regarding the locus of semantic interference. The present research does not address where exactly along the conceptual-lexical interface semantic interference originates. As

discussed previously, Norman et al. (2007) and Oppenheim et al. (2010) propose different loci of semantic interference. Specifically, Norman et al. (2007) assume that forgetting is ultimately traceable to changes to the connectivity of features within conceptual representations. However, this account neglects the potential role of the linguistic processes engaged in most recall tasks and conflates memory storage and access into a single layer. In contrast, the model of Oppenheim et al. (2010) adopts an opposite bias by ascribing semantic interference entirely to changes in the links between concepts and abstract words (lemmas). Like other language production accounts, Oppenheim et al. do not consider the possibility of dynamic changes in conceptual representations themselves, though it is uncontroversial to assume that adaptive learning process also occur in the conceptual stratum (e.g., Lambon-Ralph et al., 2017; Rodd et al. 2004; Oppenheim & Nozari, 2024). Theoretically, we see no basis for assuming either conflation. There is some work that shows patterns of retrieval-induced forgetting using nonlinguistic materials and/or nongenerative tasks (e.g., the Remember-Know paradigm, Maxcey et al., 2019), which has been interpreted to mean that semantic interference can occur without linguistic mediation. But this does not show that semantic interference in the linguistically mediated conditions of both memory and language production experiments is non-linguistic. Rather, the same or similar learning principles may operate over different representations. We do not yet know how much of interference in linguistically mediated generation occurs in the conceptual (semantic memory) stratum versus in mappings between concepts and lexical representations.

Thus, the final and most critical recommendation of this article is the development of a computational model that includes dynamically adjustable conceptual feature configurations (Norman et al., 2007) as well as links between the conceptual stratum and lexical units (as in

Oppenheim et al., 2010). The successes of both types of models suggest that they capture important semantic interference processes, but we simply do not know what the division of labor is between intra-conceptual and conceptual-lexical processes, or how this may vary with different tasks and procedures. An elaborated model, in conjunction with directed empirical investigation, should serve as a primary goal of future work.

Conclusion

In summary, this paper makes a case for unifying the study of retrieval-based semantic interference in the fields of language production and memory. Both manifestations of interference reflect the long-term consequences of activating semantic competitors, and both fields are grounded in conceptual-lexical retrieval. We therefore argue that an integrated account of conceptual-lexical retrieval removes unnecessary obstacles to a more complete understanding of semantic interference. Such an integration sets the stage for addressing important unresolved issues such as determining the relative contributions of intra-conceptual adaptive processes and conceptual-lexical adaptations to semantic interference in a variety of circumstances.

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Declaration of Interest Statement

The authors report no conflict of interest.

Data Availability Statement

Materials, by-trial data, and analysis code are openly available on OSF.

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Component 2: Submitted Manuscript

Adaptive Learning After Semantic Interference: Does Interference Promote Enhanced Relearning?

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Abstract

Generative activity can interfere with later retrieval of related concepts and words. This *semantic interference* has been ascribed to long-term adaptive learning mechanisms that promote access to selected representations and hinder access to coactivated competitors (Oppenheim et al., 2010; Norman et al., 2007). The long-term consequences of this downregulation remain under investigation. Of particular interest here, some computational accounts posit that the punishment doled out to coactivated competitors may actually serve as a catalyst for robust relearning in comparison to never-punished controls (Hulbert & Norman, 2015). There is currently limited behavioral evidence in support of this *enhanced relearning* view. The present work uses an integrated conceptual-lexical approach to assess how adaptive learning processes unfold during generation of taxonomically related words in each phase of a modified retrieval practice and relearning design (see Hambric & O'Séaghdha, under review; Storm et al., 2008; Hulbert & Norman, 2015). Category-stem cued retrieval was employed in initial learning and relearning phases, and continuous picture naming was employed in the final assessment phase to assess generality of modulated access. In each phase, there was cumulative semantic interference across category member ordinal positions. The relearning phase also showed a pattern of interference for related items (compared to control) that dissipated across each repetition, but no emerging enhanced relearning. The final assessment phase showed persistent semantic interference in the absence of relearning, but naming was equivalent for activated and unactivated control conditions that were subjected to relearning. Thus, there was no evidence of enhanced relearning for previously punished representations. Unexpectedly, cumulative interference was increased rather than decreased in both conditions after relearning. These results provide a detailed window into the temporal dynamics of learning and relearning in conceptual-

lexical access. They suggest that the relearning of recently punished competitors is not enhanced, at least not within the context of restoring accessibility of well learned conceptual-lexical links.

Introduction

Interference is routinely observed when retrieving representations amidst semantically related competitors. This *semantic interference* is a focus of both language production and semantic memory literatures, and the factors that elicit long-term retrieval difficulty have been intensively researched (e.g., Levelt et al., 1999; Anderson et al., 1994; Anderson, 2003; Damian et al., 2001; Howard et al., 2006; Abdel Rahman and Melinger, 2011; Rose et al., 2018; Hambric & O'Séaghdha, 2023). In addition, computational models have explained this phenomenon through adaptive learning mechanisms that modulate the connectivity across and within coactive semantic competitors (Howard et al., 2006; Oppenheim et al., 2010; Norman et al., 2006; Norman et al., 2007). However, much less research has focused on the question that naturally follows: once we experience interference, how long does it last, and how does it impact further learning?

Past findings across the memory and language production literatures have demonstrated that interference can persist over extensive stretches of unrelated items (e.g., Howard et al., 2006; Oppenheim et al., 2010; but see Schnur, 2014), and across extended time periods (Storm et al., 2012; Tandoh & Naka, 2007). But how and when, exactly, does *relearning*, or the restoration of accessibility, occur? The necessity of relearning is obvious-- if adaptive learning processes downregulate access to the competitor 'cat' when generating the target 'dog,' that hardly means that access to 'cat' should be hindered in perpetuity. Yet, to date, there has been very little empirical investigation into the dynamics underlying the restoration of conceptual-lexical access following semantic interference. Only a limited amount of research within the *retrieval-induced forgetting* (RIF) literature has addressed this question directly, with the current evidence indicating that merely re-exposing downregulated items is sufficient to completely ameliorate

interference (Storm et al., 2008; Storm & Soares, 2022; Hulbert and Norman, 2015). Interestingly, there is also tentative evidence of *accelerated relearning* of these representations. That is, whereas competition during generation causes interference, it has been proposed that exposure to interference may promote "accelerated relearning" of the previously downtrodden representations, thereby making them subsequently hyper accessible in comparison to never-punished controls (Storm et al., 2008; Hulbert & Norman, 2015). Rather than an accelerated pace of relearning, the term "accelerated relearning" refers to learning that makes a given representation more accessible than it was prior to experiencing interference. To clarify this idea, I will refer to the phenomenon of heightened access after interference as *enhanced relearning*. The idea that interference may promote later learning benefits may seem counterintuitive, but this supposition is consistent with past research regarding "desirable difficulty" during learning, which is thought to promote deeper conceptual processing (e.g., Bjork and Kroll, 2015; Patra et al., 2022), as well as with imaging research, discussed below, in which competitive retrieval promotes increased pattern separation in the hippocampus (Ritvo et al., 2019; Favila et al., 2016; Schachter et al., 2015). However, the behavioral evidence in support of enhanced relearning is quite limited, and crucial questions remain unanswered. Specifically, it is currently unknown whether enhanced relearning occurs in a naturalistic language production context and how relearning unfolds over time.

The premise of this paper is that the perspectives and tools from the language production literature are well poised to illuminate detailed dynamics of relearning that are opaque in the memory retrieval paradigms where enhanced relearning has been posited. Language production entails retrieval and selection of both concepts and words, and each new word generation instance can be assessed using highly sensitive latency measures. Moreover, language production

may provide a more ecological test of enhanced relearning by relying on "native" conceptual-lexical mappings. The present study combines elements of memory research design with language production assumptions and procedures (Hambric & O'Séaghdha, under review) to assess how adaptive (re)learning unfolds across generation instances and the possible benefits of overcoming past interference.

Semantic Interference

Across several domains, semantic retrieval is known to impair later access to activated but unselected relatives (e.g., Blaxton & Neely, 1983; Anderson et al., 1994; Storm et al., 2006; Damian et al., 2001; Howard et al., 2006, Rose et al., 2017). To date, investigations into this fundamental characteristic of cognition remain segregated in different fields, and integration efforts have mostly been limited to brief commentaries on the similarity of the two phenomena (e.g., Oppenheim et al., 2010; Navarrete et al., 2021). However, recent pioneering work in our own lab (Hambric & O'Séaghdha, 2022; Hambric & O'Séaghdha, under review) has demonstrated the commonality between semantic interference in word production and retrieval-induced forgetting in semantic memory.

Within the field of language production, semantic interference is measured as impaired production of picture names after generating the names of related pictures. More specifically, in the *continuous picture naming* paradigm, sets of categorically related pictures are intermixed into one continuous sequence, but internally structured such that category members appear evenly throughout the sequence (Howard et al., 2006). The typical observation is *cumulative interference*, in which naming latencies increase incrementally across category member ordinal positions (e.g., Howard et al., 2006; Rose et al., 2017; Schnur, 2014). It has been posited that the cumulative interference is due to an adaptive learning mechanism acting on the connectivity

between conceptual features and lemmas (Howard et al., 2006; Oppenheim et al., 2010). More specifically, conceptual-lexical connections to generated words are strengthened, while those to competing lemmas are weakened. Critically, this hinders the production of these competing words when they appear later on in the sequence (Oppenheim et al., 2010).

In the typical *retrieval practice paradigm* in the memory literature, participants are first introduced to multiple sets of related category-exemplar items (DRINKS – bourbon, DRINKS – tequila, FRUIT – orange, etc.; Anderson et al., 1994). They then (typically) undergo a Generation Phase comprising category-stem cue retrieval for half of the items from a subset of the categories (e.g., DRINKS – bo____), followed by a filled retention interval of 15-20 minutes. In a Final Assessment Phase, participants undergo further category-stem cue retrieval comprising three conditions[3]: The Generated condition contains items that were retrieved in the Generation Phase (e.g., DRINKS – bourbon), the Activated condition comprises items from the same category as Generated items that were not cued for retrieval (e.g., DRINKS – tequila), and the Control condition contains items that were only activated in the initial Familiarization ("Study") Phase (e.g., FRUIT – orange). Note that here we are using the more transparent labels proposed by Hambric & O'Séaghdha (under review). The effect of interest is that retrieval is impaired in the Activated condition relative to the Control condition. This *retrieval-induced forgetting (RIF) effect* is often attributed to downregulatory mechanisms that act during the initial Generation Phase (Anderson et al., 1994; Anderson & Spellman, 1995; Anderson, 2003; Norman et al., 2007; but see Jonker et al., 2012). More specifically, in the model developed by Norman et al. (2007), an algorithm identifies weak aspects of the target memory and overactive aspects of

[3] In the retrieval induced forgetting literature, the Generated condition corresponds to "Rp+", the Activated condition corresponds to "Rp-", and the Control condition corresponds to "Nrp".

competitors during the Generation Phase. A mechanism then strengthens the internal connections within the target memory and weakens them within competitors, thus promoting future pattern completion for targets and hindering it for competitors. Thus both Oppenheim et al. (2010) and Norman et al. (2007) modulate connective links based on the recent generation of semantic competitors, although this modulation is applied to conceptual-lexical links versus intra-conceptual featural links, respectively. However, given that either model focuses on a level of processing left underspecified in the other, it is possible that the broader phenomena of semantic interference may be more fully accounted for by a unified framework.

Hambric & O'Séaghdha (under review) explicitly made the case for integration and provided a proof-of-concept experiment that utilized language production measures in combination with a retrieval-induced forgetting design. Using the multiphase design of the retrieval practice paradigm, the experiment measured the effect of category member ordinal position on latencies in the Generation Phase and implemented a continuous picture naming sequence in place of the Final Assessment Phase. In the Generation Phase, they observed cumulative semantic interference, in which latencies increased linearly across ordinal positions, just as reported for continuous picture naming in the language production literature. Critically, they also found that pictures related to previously generated targets (Activated condition) took significantly longer to name than in the Control condition, especially in earlier ordinal positions. They thus found a retrieval-induced forgetting effect in picture naming latencies and showing that the downregulation of semantic competitors that occurs during category-stem cue retrieval also affects picture name (lexical) accessibility. These findings suggest that both literatures are studying different facets of the same phenomenon, and more integrative efforts are required to elucidate the dynamics of interference in semantic retrieval. the present experiment is part of a

larger effort to synthesize language production and memory accounts of retrieval-driven adaptive learning. In the spirit of integration, I will henceforth refer to both semantic interference in language production and retrieval-induced forgetting using the umbrella term of *retrieval-induced semantic interference*. Following the proof-of-concept provided by Hambric & O'Séaghdha (under review), the current work extends the scope of the integrated approach by providing a fine-grained temporal analysis of how adaptive learning processes restore conceptual-lexical access after interference, as well as investigate if accessibility is enhanced for recently punished semantic competitors.

Enhanced Relearning

Adaptive learning is thought to have long-lasting effects (Hambric & O'Séaghdha, under review; Howard et al., 2006; Storm et al., 2012; but see Schnur, 2014). In particular, downregulation of semantic competitors fundamentally entails representational change, even if it is not yet clear if this change occurs at the level of conceptual-lexical links or to the links between intraconceptual features (see Hambric & O'Séaghdha, under review, for discussion). In short, access to a recently downregulated representation should fundamentally differ from a never-punished control. Critically, however, the long-term consequences of retrieval-driven downregulation remain understudied, particularly how past interference may affect subsequent relearning.

Storm et al. (2008) provided one of the earliest investigations into the long-term consequences, and possible benefits, of retrieval-driven semantic interference. Specifically, they sought to examine how re-exposure to recently punished semantic competitors would affect subsequent accessibility (in comparison to controls). In their view, interference is due to a temporary change in retrieval strength but does affect the actual integrity of the underlying

representation (Storm et al., 2008). Since forgetting only reflects weakened retrieval strength, simply re-encountering (relearning) Activated items should fully restore access to these items. In addition, they posited that related generation supports overall storage strength, and since heightened storage strength is thought to support overall relearning, relearned Activated items may become even more accessible than relearned Controls, in it that they would exhibit *enhanced ("accelerated") relearning* (Bjork & Bjork, 1992; Storm et al., 2008).

In their design, participants completed a Generation Phase followed by a "Relearning" Phase, which entailed re-exposure to a subset of Activated and Control category-item word pairs. The number of generative retrieval and relearning blocks varied across subgroups of participants, but all participants completed the same Final Assessment Phase made up of a single category + stem cue prompt for each target item. While the "Unrelearned" (i.e., baseline) conditions displayed the typical pattern of impaired recall for the Activated condition relative to Control (retrieval-induced semantic interference), the retrieval-induced cost was absent in the Relearning conditions. Descriptively, relearned Activated items were recalled at a slightly higher rate than controls, and relearning led to greater retrieval benefits (compared to unrelearned baselines) for the Activated condition compared to controls. However, the critical comparison is that between relearned Activated and Control conditions, but these conditions were not significantly different. Thus while these results indicate that relearning can completely eliminate interference, there is limited evidence in favor of enhanced relearning for previously downregulated representations. The erasure of RIF following relearning has recently been replicated by Storm and Soares (2022), with additional evidence that amelioration of interference is independent of the number of generative retrieval episodes in which competitors were downregulated.

Hulbert and Norman (2015) revisited the topic of enhanced relearning from a representational change perspective. Although the behavioral evidence of Storm et al. (2008) was tenuous at best, the authors suggested that the idea of enhanced relearning for downregulated semantic competitors is interesting because it is consistent with contemporary computational neuroscience research on neural differentiation processes in learning (see also Schapiro et al., 2012, Wammes et al., 2021). More specifically, the authors conceptually integrated the neural differentiation capabilities of Norman et al.'s (2006) broader model of competition-dependent learning and the adaptive learning of Norman et al. (2007), discussed above, which was simulated directly within the retrieval practice paradigm. They reasoned that retrieval from memory strengthens the internal connections of features within items, while suppression by competing items entails weakening of internal connections, particularly connections among features shared with the competing concepts. What happens, then, when a weakened item is next encountered? The authors posited that when this item is reactivated (through re-exposure), additional unweakened item-specific features are engaged through spreading activation processes. As a result, the collection of features is now more distinct than it was prior to downregulation, such that it is *differentiated* from previously overlapping, semantically related representations. This differentiation results in heightened discrimination between representations, which entails heightened accessibility for relearned Activated items relative to never-punished Controls.

To test this account, Hulbert and Norman (2015) implemented a similar design to Storm et al. (2008) but with a few notable changes. First, and importantly for the hypothesis, they measured BOLD fMRI responses during the procedure, with an explicit focus on representational similarity analysis within the medial temporal lobe. In addition, they used a

more difficult episodic learning approach to heighten hippocampal network learning. Specifically, they made generation more competitive by constructing sets of individual pictures of the same animal paired with a specific name, and all of the names shared the same onset (e.g., Odin the Otter, Olaf the Otter, etc.). This is a departure from the superordinate category + exemplar structure typically used in studies of semantic interference. In their procedure, participants were first familiarized with all items, followed by generative memory retrieval (followed by correct name presentation) of items assigned to the Generated condition. Activated and Control items were also presented in this phase. However, they were presented with the correct name immediately *prior* to retrieval, thus reducing the generative activity of these items. Participants then completed a second familiarization ("restudy") phase containing all items prior to the final assessment phase, where they were asked to correctly recall the name of each picture a single time. Despite methodological deviations, their behavioral results were mostly consistent with Storm et al. (2008). They observed the typical retrieval-induced interference effect for unrelearned conditions as well as marginally better naming performance for the Relearned Activated condition relative to Control (i.e., enhanced relearning). Critically, they also found that decreased pattern similarity in the hippocampus was positively correlated to relearning for Activated items, such that the more dissimilar the patterns of activity grew over time, the greater the memory benefit for relearned Activated items (Hulbert & Norman, 2015). Taken together, these results provide some tentative evidence that competition during generation promotes heightened neural differentiation, which in turn supports later retrieval amidst associated representations (Favila et al., 2016; Schlichting et al., 2015; Ritvo et al., 2019; see also Schapiro et al., 2017; Wammes et al., 2021). However, it is still unclear how robust this phenomena

actually is, how relearning itself unfolds over time, and if the benefits of enhanced relearning dissipate over subsequent generations.

A detailed differentiation account, which subsumes the integration of Norman et al. (2006) and Norman et al. (2007) developed by Hulbert & Norman (2015), has been computationally implemented as the Nonmonotonic Plasticity Hypothesis (NMPH, Ritvo et al., 2023, Ritvo et al., 2019; Newman and Norman, 2010). This account makes broad claims about the role of neural integration and differentiation in memory. As the name implies, the hypothesis proposes that the effect of coactivation follows a nonmonotonic curve, such that moderate coactivation among competitors leads to differentiation of representations (as is proposed to occur in Hulbert & Norman, 2015), while a high coactivation is associated with their integration. This model has chiefly been applied to highly constrained memory paradigms that focus on novel learning episodes, rather than to the pre-existing semantic structures used in the study of retrieval-induced semantic interference. As in Norman et al. (2007), this model also fails to consider the intrinsic semantic competition that routinely occurs during lexical retrieval and selection, both of which are required by the verbal recall measures used in many memory paradigms. Given the pre-existing interconnectivity among (taxonomically) linked conceptual-lexical representations, language production may thus provide a robust test of the applicability of these differentiation processes both in semantic memory and in a more ecological speaking context.

Present Study

The purpose of the present study is to illuminate how conceptual-lexical access is restored following semantic interference using an integrative conceptual-lexical perspective. Specifically, I extended the methods developed by Hambric & O'Séaghdha (2022) and Hambric

& O'Séaghdha (under review) to investigate how adaptive (re)learning unfolds across both related generation instances and repetitions, and in particular to assess if relearning results in heightened accessibility for recently punished competitors in a naturalistic word production context.

Although the theoretical frameworks are compelling, the current behavioral evidence of enhanced relearning following semantic interference is quite weak, and several specific questions remain unanswered. First, as discussed above, it is unclear if differentiation among coactive representations, and by extension enhanced relearning of recently punished competitors, occurs in the over-learned conceptual-lexical mappings engaged during word production or if enhanced relearning chiefly applies to newly learned associations. The present study thus paired the typical (superordinate) category-stem cue generation with generative picture naming methodologies to assess if interference driven by semantically related retrieval promotes enhanced relearning of conceptual-lexical representations.

Second, it is unclear what type of processing is optimal for enhancing conceptual-lexical access following downregulation. Storm et al. (2008), Storm & Soares (2022), and Hulbert & Norman (2015) all used simple re-exposure ("restudy") in which participants reread category + exemplar pairs. It is worth noting here that the "restudy" moniker derives from the memory literature and is thus awkward in a language production context. Rather, "familiarization" is typically used to refer to the procedure of introducing pictures with their (known) names. Given that the present work presents pictures in the initial "study" sequence and uses the production of isolated, known picture names in the final assessment phase, I will refer to the overt presentation of the designated name during relearning as *refamiliarization*. Some work within the language literature supports the benefit of using this type of comprehension to strengthen lexical access for

production (e.g., Francis et al., 2022). However, other work has shown only picture name generation, as opposed to simply naming words, in a continuous naming sequence elicits cumulative interference, thus suggesting that generation is necessary to engage long-term adaptive learning processes (Belke, 2013; O'Séaghdha et al., in prep). This is in line with the testing effect literature, which argues that complete generation from memory may encourage more relearning than that observed with refamiliarization procedures (Carpenter, 2011; Pyc & Rawson, 2010). Assuming the latter view, I implemented category-stem cue generation + refamiliarization during the Relearning Phase to promote more robust adaptive learning. I do note that generation will presumably induce interference across the relearning sequence. This poses an interesting question of how relearning may unfold in the context of new interference but could cloud the expected differences between previously downregulated and control conditions. I thus implemented a carefully controlled continuous naming design to assess intraphase interference so that it might be disentangled from the cross-phase adaptative learning processes of interest.

Lastly, it is unclear how enhanced relearning unfolds across time and how long it bolsters accessibility. That is, it is currently unknown how relearning unfolds across each encounter of a related category member, as well as if enhanced accessibility chiefly applies to the first generation after relearning or if it a robust, long-lasting boost to accessibility. The current methods are not equipped to address these questions. This is especially true given the aggregate estimations of retrieval success typically used in the memory literature, where the accessibility of each item is indexed by a binary success/failure in a single pass through the materials. Yet, if one were to assess enhanced relearning across multiple generations using typical retrieval measures, recall would presumably hit ceiling in the second recall attempt and provide little insight. I

suggest that this is where the language production methodologies used to study semantic interference can be very useful. Since language production methods utilize picture naming procedures where changes in accessibility are indexed by differences in production latencies, using pictures as cues and assessing latencies serves as a way to sensitively measure relative accessibility across related generations. This method is also useful in assessing how enhanced accessibility may change across regenerations of the same items and thus clarify the longevity of enhanced relearning. The current study measured the effect of ordinal position within each sequence and assessed accessibility across multiple repetitions, thus providing a window into the time course of adaptive (re)learning that is not provided by aggregate memory measures. I also note that this latency-based approach is a far more economically feasible and temporally sensitive method than the fMRI methods implemented in the Hulbert and Norman (2015) study and subsequent cognitive neuroscience studies (e.g., Schapiro et al., 2012, Favila et al., 2016).

The present experiment used a modified retrieval practice paradigm with an added relearning component. The design is comprised of four sequences with three primary phases. First, participants were familiarized with all pictures paired with their category label and name. This was done to make picture names and stems available for subsequent phases. In the following Generation ("retrieval practice") Phase, they underwent repeated category-stem cue retrieval for a subset of items from half of the categories (termed the Generated condition). During this phase, it is thought that semantically related (but uncued) representations are activated, and these representations are downregulated to facilitate generation of target items. Thus the Generation Phase uses semantically related retrieval to establish interference for the Activated condition in the following phases. Critically, in order to investigate how accessibility dynamically changes across related retrievals, the presentation of items within this phase was

internally structured to assess the effect of category member ordinal position within the sequence. In the Relearning Phase, participants underwent category-stem cue generation followed by the presentation of the correct name and picture for half of the categories previously Activated (and downregulated) in the Generation Phase (Generated-Activated condition) and half of unactivated Controls (Generated-Control condition), which were never downregulated. In this way, the comparison between the Activated and Control conditions reflects the impact of previous semantically related retrieval. In addition, the Generated-Control condition served as a later control for the effect of generation and refamiliarization during the Relearning Phase. Generation during this phase is a deviation from past enhanced relearning work but was chosen to encourage deeper semantic processing and more robust adaptive learning. These materials were also presented in structured continuous sequences three times. This generation will also incur new interference, but the assessment of ordinal positions will allow the separation of intraphase interference from the overall effect of past related retrieval. Lastly, in the Final Naming Assessment Phase, participants completed a structured continuous picture naming task containing all materials except those generated in the Generation phase (see Figure 1). Picture naming provides a sensitive test of accessibility for pre-existing conceptual-lexical representations, as well as a cue-independent method of assessing the effect of past related retrieval and relearning. Thus there were four key conditions in the final phase: The Baseline-Activated condition, containing items that were activated and downregulated by related retrieval in the Generation Phase (as in the typical RIF paradigm); the Baseline-Control condition, which entails items which were not previously affected by related retrieval, the Generated-Activated condition, in which items were subjected to interference in the initial Generation Phase and then

generated in the Relearning Phase (Generated-Activated); and finally, the Generated-Control condition, comprising unactivated items that were generated as a control in the Relearning Phase.

The predictions were as follows. As in Hambric & O'Séaghdha (under review), I expected to observe cumulative interference within each of the Generation, Relearning, and Naming Assessment Phases. This would provide evidence that downregulation accrues incrementally across both related category-stem cue and picture name generations. In the Relearning Phase, I predicted the typical RIF pattern of impaired retrieval in the recently punished Activated condition relative to Control but that this difference would be mitigated across Repetitions. Thus this phase comprised a test of RIF using the usual category-stem cue procedure as well as a way to restore conceptual-lexical access. A key prediction was also that the relearning process would gradually erase accumulated interference, such that one would be able to "see" relearning processes erase downregulatory effects across Repetitions. For the Final Naming Assessment phase, the central prediction of enhanced relearning entails the comparison between Generated-Activated and Generated-Control conditions. If enhanced relearning applies to well-learned conceptual-lexical representations, one should observe an overall facilitation for restrengthened latent competitors (Generated-Activated condition) compared to the Generated-Control condition. These items were not punished competitors in the initial Generation phase but received the same generative exposure during the Relearning Phase. As in Hambric & O'Séaghdha (under review), this difference might be greatest in the initial Ordinal Positions. Of particular interest will be to assess how stable this boost in accessibility is across Repetitions, which will add much needed detail to the effect of enhanced relearning across multiple regenerations. In addition, I also predicted a standard retrieval-induced forgetting effect in which Baseline-Activated items take longer to name than Baseline-Controls, and again that this effect

may be strongest in the initial positions. I predict that this effect will dissipate across Repetitions, thereby illustrating (again) that RIF can be overridden by subsequent generation. I also assumed an overall benefit for items that underwent repeated generation + refamiliarization in the Relearning phase, such that naming will be facilitated relative to both Baseline conditions. Lastly, if it is indeed differentiation processes that drive enhanced relearning, it follows that relearning should weaken coactivation of related set members. This reduction in coactivation during the naming of other category members should result in less downregulation for the activated-but-not-selected competitors and thus less accumulation of interference across Ordinal Positions. In this view, accumulation of interference will be reduced in the Generated-Activated condition (i.e., a flatter slope in latencies across ordinal positions).

Method

Participants

Power was estimated using both the guidelines proposed by Brysbaert & Stevens (2018), in which a reaction time experiment with repeated measures should aim for approximately 1,600 observations per condition, and the precedent of recent commensurate work in our own lab (Hambric & O'Séaghdha, under review). Given that there were 12 target trials in each condition of the critical picture naming phase, and effects were expected to be strongest in the first Repetition, 128 participants were recruited from Lehigh University in return for class credit in an introductory psychology course (12x128=1536 trials per Repetition). Due to excessive error rates (>50%, N=2) and equipment malfunctions (N=4), there were 122 subjects in the final sample used for analysis.

Materials and Apparatus

Twelve groups of eight taxonomically related items (96) were selected using the Bank of Standardized Stimuli (Brodeur et al., 2010; Brodeur et al., 2014). In a handful of cases in which there were a limited number of items in a given category, experimenter discretion was used to select additional items (N=3, N=4, in two categories, respectively). The relatedness of items in each group was established using the normative data from the Bank of Standardized Stimuli (Brodeur et al., 2010; Brodeur et al., 2014) and experimenter discretion, and additional frequency data were acquired from the LexOPS data base to ensure selected materials were as equivalent as possible in frequency (Taylor et al., 2020). The complete list of materials and selection criteria can be found on OSF (https://doi.org/10.17605/OSF.IO/HGMA8). Pictures were presented centrally and sized to approximately 4 in x 4 in (Brodeur et al., 2014). Text was presented in 14-point Corsolas font.

The experiment was programmed using E-Prime 3.0 and was conducted using a Dell OptiPlex 7020 computer with a 1908FPt 75 DPI monitor with a refresh rate of 80 Hz. Participants were seated approximately 16 inches from the screen. Voice onset times were recorded using a Psychology Software Tools 200A SR box interfaced to an ATR20 Audio-Technica microphone, situated approximately 12 inches away from the participant. Audio for the entire session was recorded using a SONY ICD-PX720 recorder.

Design

The experiment was comprised of four parts, with three key phases with linked designs. See Figure 1 for a simplified illustration of the design. The full details of the counterbalancing procedure can be found on OSF. The first part entailed familiarization of pictures of all items

with their names and category labels (see Procedure). The three experimental phases were as follows.

Generation Phase

In this phase, half (6) of the categories were assigned to the Activated condition, and the other half were assigned to the Control condition. The assignment of categories to Activated versus Control conditions was counterbalanced across experimental versions. Half of the items (4) in each of the 6 Activated categories (24 items total) were assigned to the Generation condition. Other aspects of the design followed the typical implementation of a continuous naming procedure: one item from each category was assigned to one of four quartiles, thereby allowing the assessment of the effect of ordinal position within the sequence. Items within each quartile were randomized, and the ordering of quartiles was balanced across subgroups of participants. Following previous work (Hambric & O'Séaghdha, under review), the continuous sequence was repeated three times, each time with a new ordering of quartiles with no direct repetition of quartiles between repetitions. Thus the manipulated factors in this phase were Ordinal Position (1-4) and Repetition (1-3).

Relearning Phase

The Activated condition was split in half. Half (3) of the categories were assigned to the Generated condition (12 items), and half (3) to the Baseline condition (12 items). The assignment of items to conditions was counterbalanced across subversions of the experiment. In the same way, the Control condition was divided into counterbalanced Generated and Baseline sub-conditions (12 items each). The design of this phase replicated that of the Generation phase, including the three reorganized repetitions of the sequence. Thus there were three within-subjects

factors, Memory Condition (Activated versus Control), Ordinal Position (1-4) and Repetition (1-3).

Final Picture Naming Assessment Phase

The continuous picture naming phase contained all items except those generated during the initial Generation phase. These items were excluded to avoid contamination of interference accumulation for same-category Activated items. Thus, the final phase comprised Generated ("relearned") Activated and Generated-Control conditions and previously ungenerated Baseline Activated and Baseline Control conditions, each of which contained 12 target items. A continuous design was implemented as in the prior two phases, and the sequence was again presented three times with a reordering of quartiles, and of items within them, in each repetition. Thus the factors were Memory Condition (Activated versus Control), Generation (Generated versus Baseline), Ordinal Position (1-4), and Repetition (1-3).

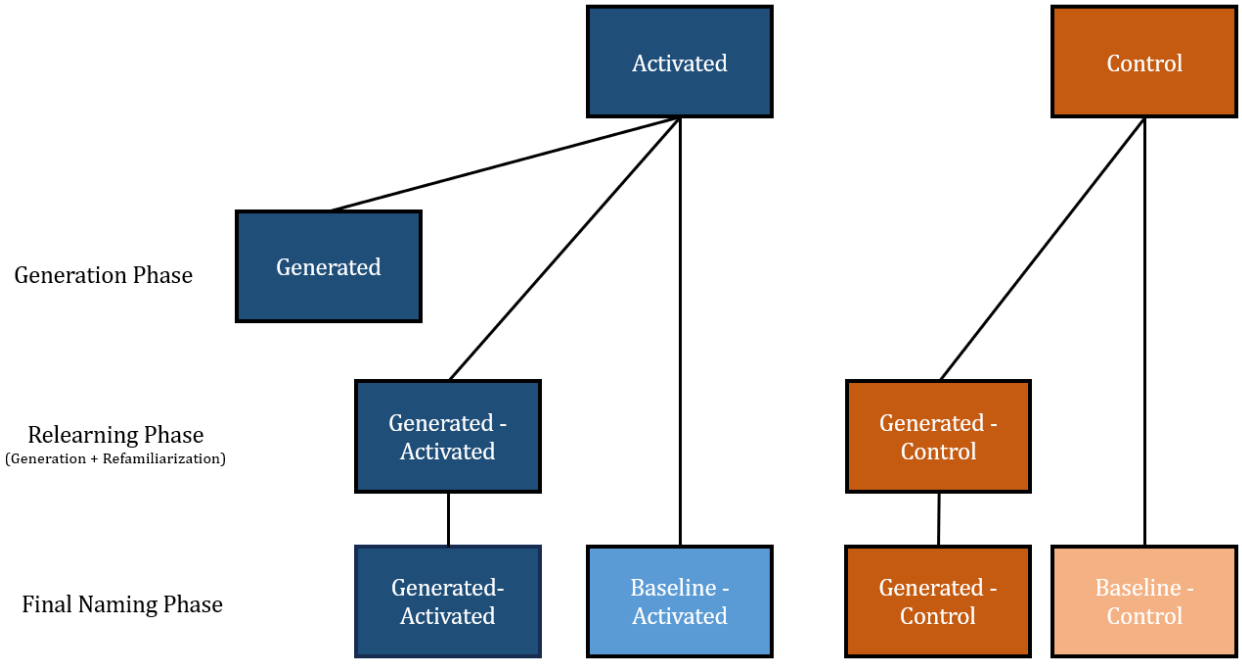

Figure 1. Simplified diagram of the design. First, half of the categories (6) were assigned to the Activated condition and half (6) to the Control condition. In the Generation phase, half of the items from each Activated category underwent repeated category-stem cue retrieval. In the Relearning Phase, half of the Activated and Control condition items were repeatedly generated (category-stem cues) and refamiliarized (with picture), while the remaining items in either condition served as corresponding Baselines. In the final phase, pictures corresponding to Generated-Activated and Generated-Control conditions, as well as not previously generated Baseline-Activated and Baseline-Control conditions, were named over three continuous sequences.

Procedure

Familiarization

Following standard practice, participants were first introduced to the materials. They were told that they would be presented with a series of everyday objects and that they would be using the information in subsequent tasks. All items used in later phases were presented as pictures with their category and name in a randomized sequence. Presenting the names with the pictures eliminates the need for active lexical retrieval but makes the designated names (as well as the category-exemplar combinations) available for the experimental phases. Thus, both the category-exemplar labels and corresponding pictures were introduced in a single pass. On each trial, a fixation cross appeared for 200 ms, followed by the presentation of a picture with the category-name combination (e.g., BIRDS – seagull) below it for 1500 ms. To ensure that the information was registered, participants read each category and picture name aloud. The experimenter provided feedback on standard pronunciation on the few occasions where it was necessary. No data were collected.

Generation Phase

In this phase, participants were instructed that they would be presented with a category-stem cue (e.g., PLANTS - tr____) on each trial and that they should complete the word matching the cue ("tree") as quickly and accurately as possible. The category-stem cues would come from the previously shown list. They were told that each cue would appear multiple times and were asked to remain silent if they did not remember the word. The stems were always the first two letters of the target name. Category-stem prompts were presented in a structured continuous sequence, and the whole sequence was repeated three times (see Design). On each trial, a fixation cross appeared for 200 ms, followed by the category-stem cue. The display lasted for 8

seconds or until a naming response was registered. The next trial began 1000 ms after the conclusion of the previous one.

Relearning Phase

Participants attempted to generate targets from category-stem cues as in the Generation Phase. Different from the generation phase, following a successful or unsuccessful retrieval, the corresponding picture appeared centrally with the designated name printed below it for 750 ms. This was done to remind participants of the correct response or to confirm that their answer was correct as well as to prepare generated items for the upcoming picture naming phase. Category-stem cues were again presented in a structured continuous sequence, and the sequence was presented with a new quartile and item ordering three times.

Final Picture Naming Assessment Phase

Participants named target pictures comprising four conditions in one continuous sequence internally segmented into quartiles (see Figure 1 and Design). On each trial, a fixation cross was presented for 200 ms followed by the printed category (e.g., BIRDS) of the upcoming picture for 750 ms. Category labels are not typically used in picture naming procedures but were used here for consistency with the Generation and Relearning phases. The target picture (without label) was then presented for up to 1500 ms or until a naming response was registered. A tone sounded and a “too slow” message appeared for 200 ms if the time limit was exceeded. Another trial began 1000 ms after the previous one. As in previous phases, the continuous sequence was repeated three times. Following the completion of this phase, participants were thanked and received an educational debriefing.

Results

Audio recordings of each session were coded off-line by the author and a trained research assistant. Trials in which a participant used an incorrect or incomplete name, responded dysfluently, or did not respond, were coded as naming errors and excluded from latency analyses. Trials in which an environmental sound set off the voice key and trials in which the reaction time was less than 250 ms were coded as invalid and excluded from all analyses. Separate linear mixed model analyses were conducted in R version 4.3.3 using the *afex* package (Singmann & Kellen, 2019). Sum-zero contrasts were set for the relevant categorical variables and F-tests for the fixed effects were conducted with Satterthwaite approximations applied to estimate the degrees of freedom. A maximal random effect approach was used (see Barr, 2013), with the constraint that models were incrementally simplified until convergence was achieved. There was no meaningful effect of the counterbalancing factors and they were therefore excluded from all analyses.

Generation Phase

Latency Analysis

Overall, generation times decreased across Repetitions ($Mean_{R1}$=1455, SE=36; $Mean_{R2}$=1332, SE=36, $Mean_{R3}$=1230, SE=36) and latencies increased over Ordinal Positions, primarily in the first Repetition, see Figure 2.

The maximal converging linear mixed model included the fixed main effects of Ordinal Position, Repetition, their interaction, and random intercepts for both subjects and items. There was a significant main effect of Repetition ($F(2, 6231)=72.54$, $p < .001$), such that naming times significantly decreased across Repetitions. There was a main effect of Ordinal Position, ($F(3,6233)=14.59$, $p < .001$), indicating that naming times increased over Ordinal Positions. This

effect was qualified by a significant interaction between Repetition and Ordinal Position ($F(6,6280)=4.22$, $p < .001$), This reflects the stronger accumulation of interference across Ordinal Positions in the first Repetition. These data replicate the findings of Hambric & O'Séaghdha (under review), showing the occurrence of cumulative interference across Ordinal Positions in latencies using the stem-completion procedure typically used in the memory literature.

Error Analysis

Overall, participants had a low error rate of 24%, with the error rate decreasing across Repetitions, R_1= 28%, R_2=23%, R_3= 21%, see Figure 3. Of the total errors, 72% were meaningful naming errors (see above). Of the naming errors, 26% were commission errors, such as semantic substitutions, and the remaining 74% were omission errors. A logistic mixed model was conducted to assess naming error likelihood across Ordinal Positions and Repetitions. The maximally converging model included the fixed main effects of Ordinal Position and Repetition, their interaction, and a random intercept for items. The effect of Ordinal Position was marginal, such that error likelihood fluctuated across Ordinal Positions without any clear linear pattern, $\chi^2=6.61$, $p = .09$. There was a main effect of Repetition ($\chi^2=16.23$, $p < .05$), reflecting that error likelihood significantly decreased across Repetitions. The interaction between Ordinal Position and Repetition was also significant ($\chi^2=16.90$, $p < .05$), such that error likelihood increased across Ordinal Positions only in the first Repetition.

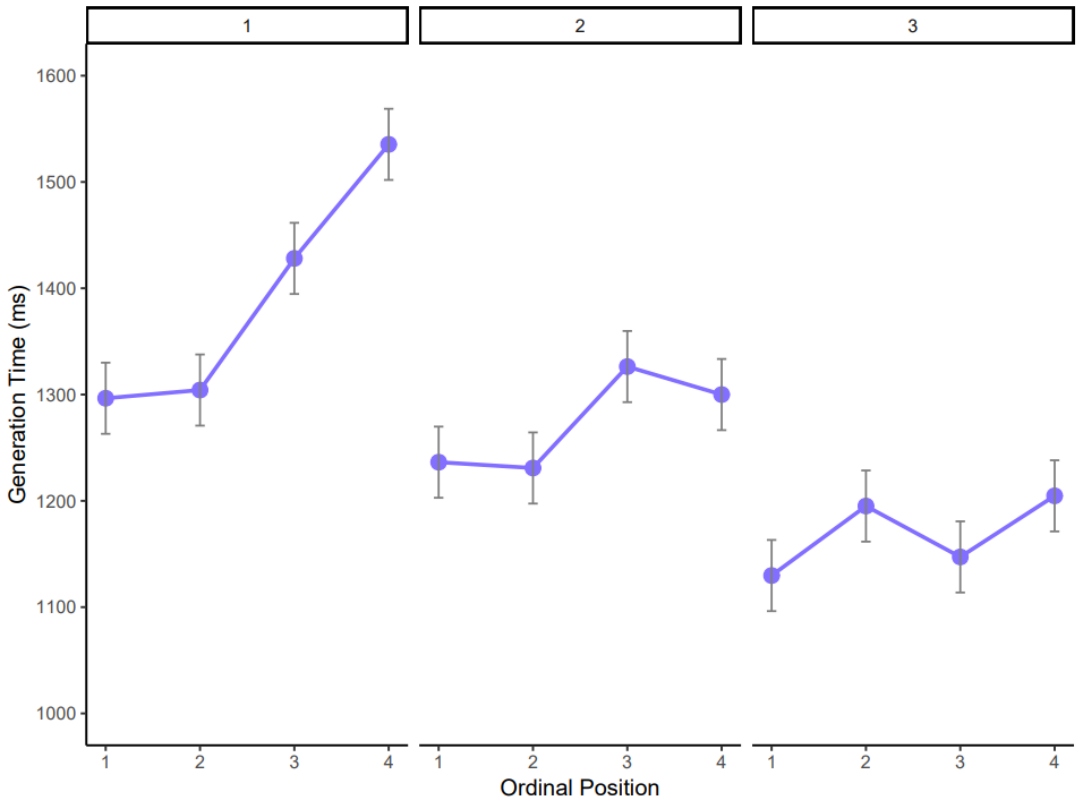

Figure 2. Generation time as a function of Ordinal Positions (1-4) and Repetitions (1-3) in the Generation Phase. Cumulative interference was reduced across Repetitions.

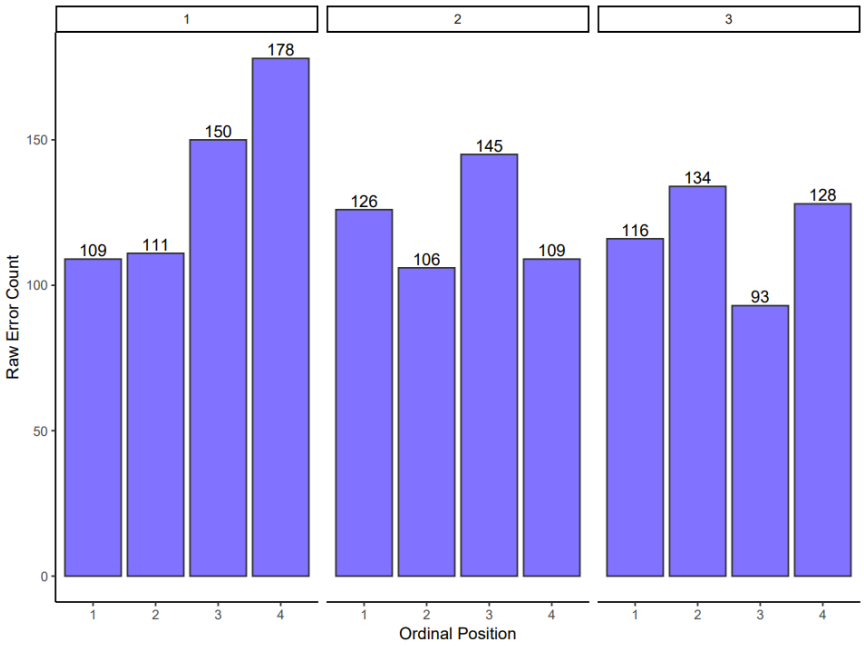

Figure 3. Error counts as a function of Ordinal Position (1-4) across Repetitions (1-3).

Relearning Phase

Latency Analysis

Descriptively, as in the previous phase, latencies increased over Ordinal Positions but decreased across Repetitions. The Activated condition responses (M =1296, SE=34) took longer to generate than Control, M=1276, SE=34 (a RIF pattern). However, these conditions converged across Repetitions, suggesting that relearning processes incrementally overrode past interference, see Figure 4.

The maximally converging linear mixed model included the fixed main effects of Memory Condition, Ordinal Position, Repetition, their interactions, random intercepts for both subjects and items, and a random slope for Memory Condition among subjects. As in the previous phase, latencies significantly decreased over Repetitions, $F(2,6774)=351.15$, $p < .001$. There was a main effect of Ordinal Position ($F(3,6768)=9.80$, $p < .001$), in which latencies increased across Ordinal Positions. Contrary to the previous phase, the interaction between Repetitions and Ordinal Position was not significant ($F(6,6811)=0.88$, $p > .05$), indicating that cumulative interference was stable across Repetitions. The main effect of Memory Condition ($F(1,113)<1$) as well as its two-way interactions with Repetition ($F(2,6768)=1.14$, $p > .05$) and Ordinal Position ($F(3,6769)<1$), were not significant. The interaction between Memory Condition, Ordinal Position, and Repetition was also not significant, $F(6,6771)<1$). While I predicted significantly impaired generation in the Activated condition relative to Control, the lack of a significant RIF effect here may be due to lack of power.

Error Analysis

In this phase, the overall retrieval error rate was 26%, with the error rate greatly decreasing across Repetitions, R_1=33%, R_2=9%, R_3= 5%, see Figure 5. This significant decrease

in errors is presumably due to both repetition and the presentation of the correct word (and picture) after each trial. There was no apparent difference in the retrieval error rate of relearned Activated items (16%) compared to Control (15%). Of the total errors, 76% were naming errors. Of these salient errors, 27% were commission errors and 73% were omission errors. A logistic mixed model was conducted to assess naming error likelihood across Memory Condition, Repetitions, and Ordinal Positions. Due to data sparsity, the maximally converging model included the fixed main effects of Memory Condition, Repetition, their interaction, and a random intercept for items. The effect of Memory Condition was not significant (χ^2=0.45, p >.05), reflecting that errors were not more likely in the Activated than in the Control condition. There was a large main effect of Repetition (χ^2=1086.14, p < .001), reflecting that errors drastically decreased after participants were given the correct words and corresponding pictures in the first pass. The interaction between Memory Condition rand Repetition was not significant, χ^2=0.15, p > .05. Overall, these findings show that while intra-phase cumulative interference was stable across Repetitions, accessibility generally increased across regenerations in both Memory Conditions. The overall effect of past related retrieval was not detected with the current power, although the descriptive pattern indicated that the Activated and Control conditions converged across Repetitions.

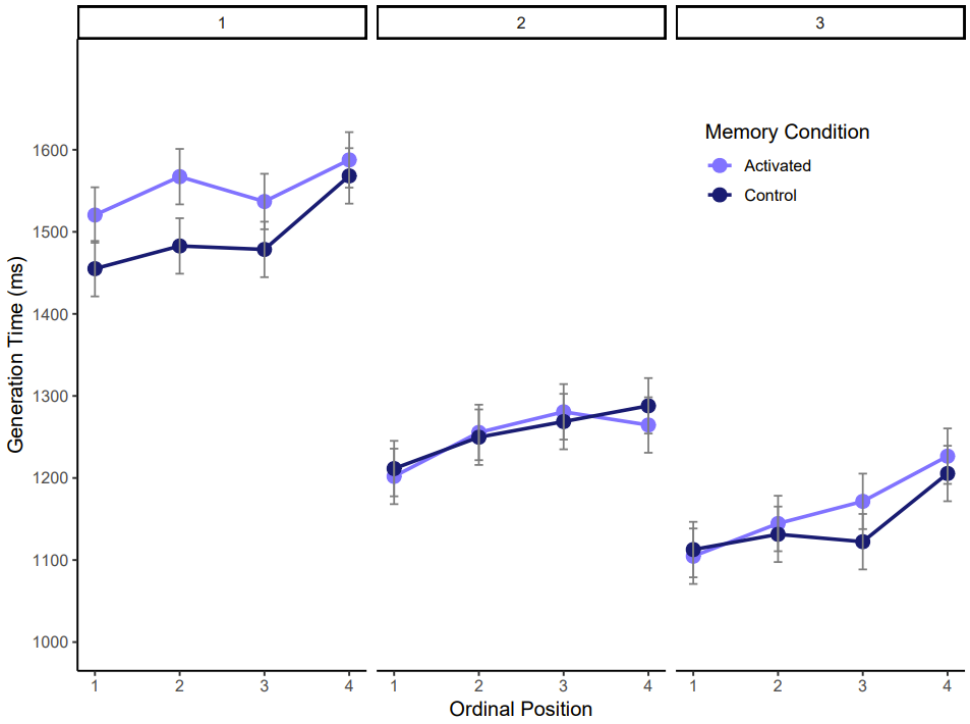

Figure 4. Generation time in previously Activated and Control conditions as a function of Ordinal Position (1-4) and Repetition (1-3). Interference accumulated for both Activated and Control conditions in all Repetitions.

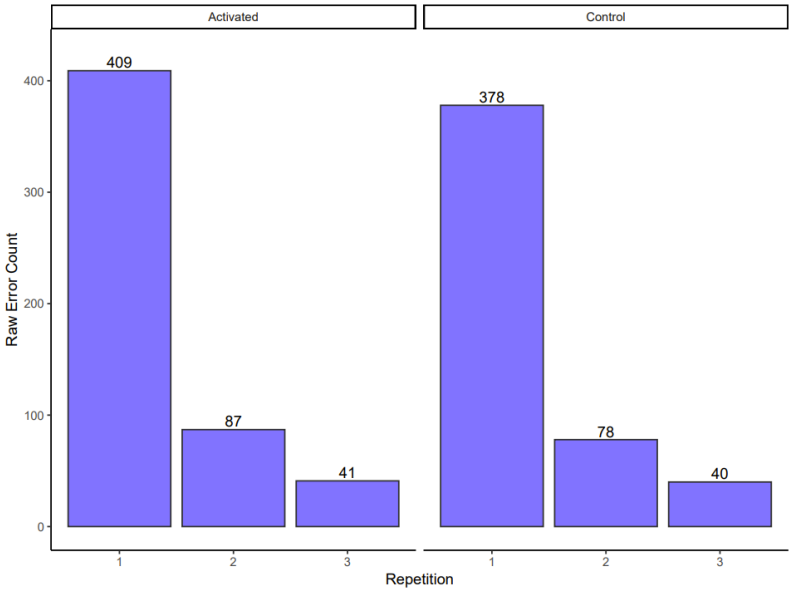

Figure 5. Errors as a function of Memory Condition and Repetition (Ordinal Positions collapsed).

Final Picture Naming Assessment

Latency Analysis

Descriptively, picture naming times decreased across Repetitions (R_1=732, SE=9, R_2=686, SE=9, R_3=679, SE=9), and were faster in Generated conditions (M=673, SE=9) than Baseline (M=725, SE=9). In the Baseline condition, the Activated condition (M=731, SE=9) naming latencies were longer than Control, M=720, SE=9. In the Generated conditions, there was no meaningful difference between the Activated (M=671, SE=9) and Control (M=674, SE=9) conditions. Given that the two conditions converged across Repetitions in the Relearning Phase, this is not surprising. Across conditions, latencies tended to increase across Ordinal Positions (see Figures 5 and 6).

The maximally converging linear mixed model included the fixed main effects of Repetition, Memory Condition, Generation, Ordinal Position, their interactions, and random intercepts for both subjects and items. As expected, there was a significant main effect of Repetition, in which latencies significantly decreased over Repetitions, $F(2,15807)=227.63$, $p < .001$. There was also a significant main effect of Generation, in which generation and refamiliarization during the Relearning Phase led to faster naming times than Baseline, $F(1,15811)=549.05$, $p < .001$. This may be due to both the repeated generation and picture exposure during the Relearning Phase. There was also a significant main effect of Ordinal Position, such that, collapsed over Repetitions, there was an overall increase in latencies across Ordinal Positions, $F(3,15807)=26.70$, $p < .005$. This reflects that cumulative interference was stable across repetitions. Critically, there was a significant interaction between Memory Condition and Generation, $F(1,15810)=8.73$, $p <.05$. This interaction reflects that the difference between Activated and Control conditions depended on whether these conditions underwent

generation + refamiliarization in the Relearning Phase. More specifically, pair-wise comparisons with Tukey corrections indicated that the Baseline-Activated condition took significantly longer to name than Baseline-Controls (a typical retrieval-induced forgetting pattern, z =3.16, p <.05), but Generated-Activated and Generated-Control conditions did not significantly differ, z =-0.99, p >.05. Thus, this key finding indicates that while retrieval-induced interference was observed for the Baseline condition, this interference was erased by generation during the Relearning Phase. Moreover, the lack of facilitation for the Generated-Activated condition compared to Generated-Controls indicates that enhanced relearning was *not* observed for recently punished competitors.

There was also a significant interaction between Repetition and Generation (F(2,15807)=145.01, p < .05), indicating that the benefit of Generation (relative to Baseline) decreased across Repetitions. That is, it took only one repetition to nearly equate the two conditions. Interestingly, there was also a significant interaction between Generation and Ordinal Position, F(3,15807)=4.95, p < .05. The prediction based on adaptive learning (e.g., Hulbert & Norman, 2015; Ritvo et al., 2019) was that differentiation processes during relearning would decrease coactivation of relatives during subsequent picture naming, thus leading to less accumulation of interference in the Generated-Activated condition relative to both Baseline conditions. I observed the opposite pattern, such that there was heightened cumulative interference following generation + refamiliarization, regardless of Memory Condition. Given that there was no effect of prior related retrieval (i.e., Memory Condition), this increased cumulative interference reflects the impact of recent generation rather than relearning processes. There was also a significant interaction between Repetition and Ordinal Position (F(6,15849)=2.87, p < .05), as well as a significant three-way interaction between Generation,

Repetition, and Ordinal Position, $F(6,15807)=2.40$, $p < .05$. These significant effects suggest that for conditions undergoing generation + refamiliarization, cumulative interference was robust across Repetitions, while the same stability was not observed for the Baseline conditions. There was also a significant four-way interaction between Repetition, Memory Condition, Generation, and Ordinal Position, $F(6,15807)=2.32$, $p < .05$. This complex interaction is difficult to interpret and is best understood by through the collection of lower level interactions.

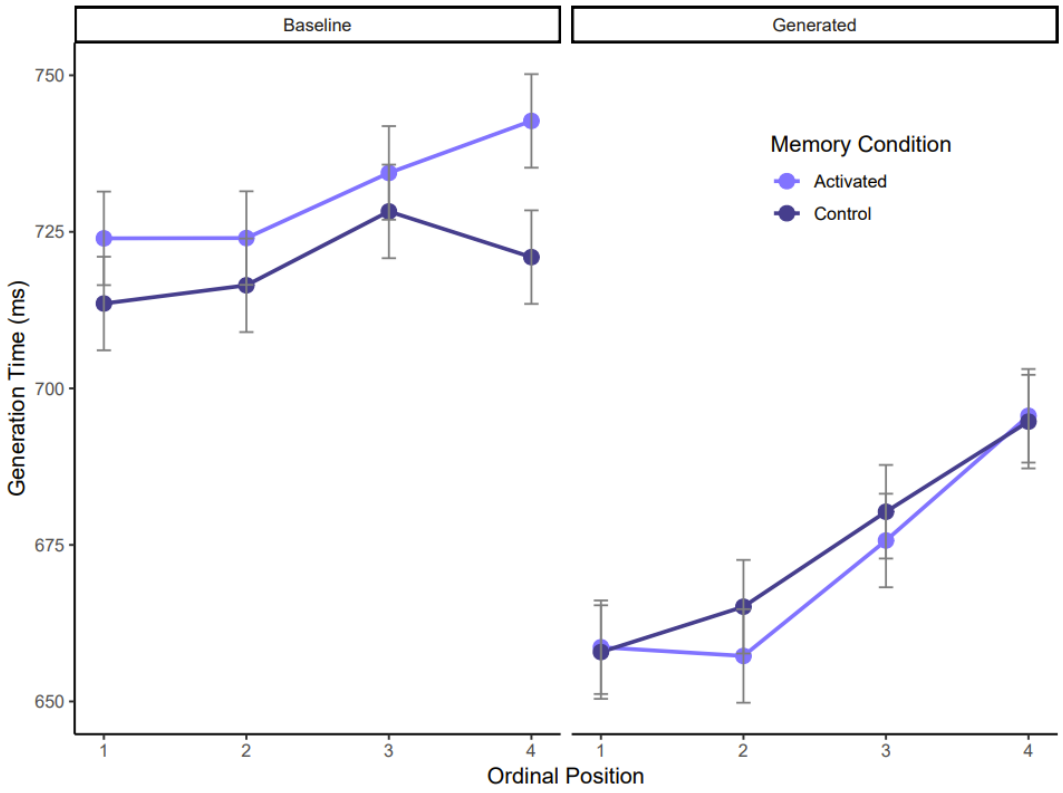

Figure 6. Picture naming times in Final Assessment Phase. Activated and Control Baseline and Generation conditions as a function of Ordinal Position. Repetitions are collapsed.

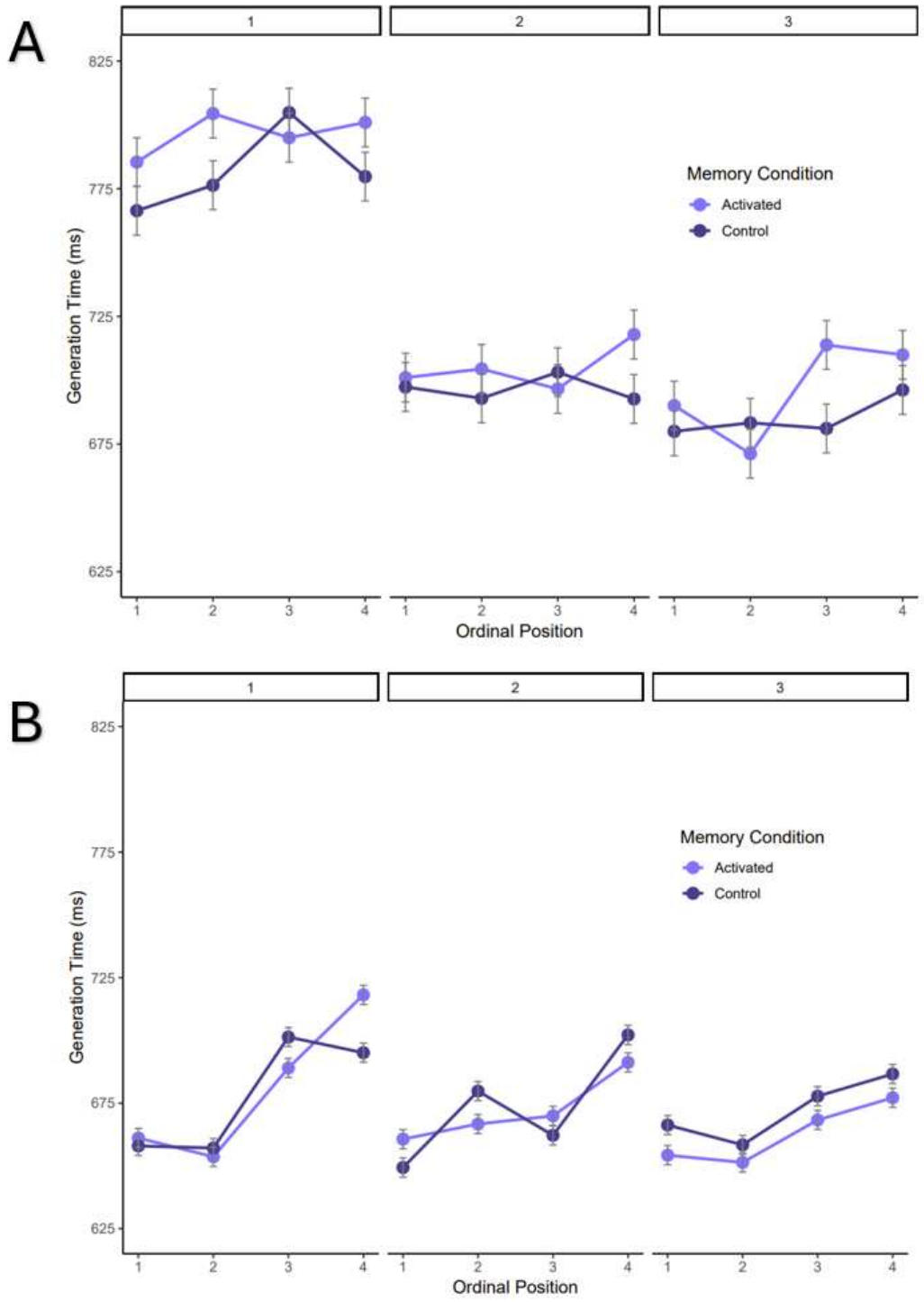

Figure 7. Picture naming latencies in the Final Naming Phase in Repetitions 1-3, A for Baseline Activated versus Control conditions, and B for Generated-Activated versus Generated-Control conditions.

Error Analysis

The overall error rate in this phase was 7.7%, and errors decreased across Repetitions, R_1=9.8%, R_2=6.8%, R_3=6.6%, see Figure 7. A logistic mixed model of salient naming errors was conducted to assess error likelihood as a function of Memory and Generation conditions. Due to data sparsity, the maximally converging model included only the fixed main effects of Memory Condition and Generation, their interaction, and a random intercept for items. There was no main effect of Memory Condition (χ^2=1.13, p >.05) but the effect of Generation was significant (χ^2=46.08, p < .001), indicating that error likelihood was significantly reduced by the relearning phase process. The interaction between Memory Condition and Generation was also insignificant, (χ^2=0.84, p >.05). Thus, although there was a retrieval-induced forgetting pattern of increased latencies in the Baseline-Activated condition relative to Baseline-Control, we did not observe the same pattern in errors. Consistent with the latency data, there was no difference in errors for Generated-Activated relative to Generated-Control conditions.

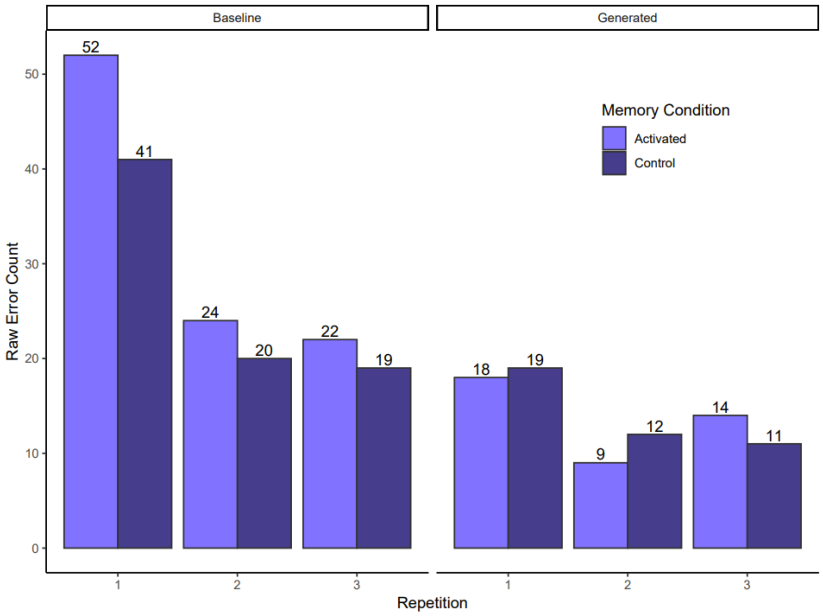

Figure 8. Errors as a function of Memory Condition and Repetition (collapsed across Ordinal Positions).

Discussion

Past generative activity is known to cause interference for semantically related conceptual-lexical representations, but less is known about how and when access to these downregulated representations is restored. In addition, research has suggested that semantic interference may serve as a catalyst for more robust learning (Storm et al., 2008; Hulbert & Norman, 2015; Patra et al., 2022; Middleton et al., 2016; Ritvo et al., 2019). Specifically, the term *enhanced relearning* refers to the phenomenon in which items initially subjected to retrieval-driven interference may benefit more from subsequent relearning than unpunished controls (Storm et al., 2008; Hulbert & Norman, 2015). The present study adopted an integrated conceptual-lexical approach to illuminate the restoration of conceptual-lexical access after downregulatory adaptive learning and assess if relearning is enhanced following interference.

The present study used a modified version of the retrieval practice + relearning paradigm in which phases were internally structured to assess the cumulative effect of each related

retrieval instance on both latencies and errors, a method that is typically implemented within language production research. After an initial Familiarization sequence, a Generation ("retrieval practice") Phase was presented in which half of the items from half of the categories were retrieved using category-stem completion cues. Critically, a "Relearning" Phase followed in which half of items related to previously generated items (Activated condition) and half of the unrelated items (Control Condition) were generated using category-stem cues and then presented with their correct name and picture. In the Final Naming Assessment Phase, a repeated continuous picture naming procedure was implemented to assess the effect of past related generation for Baseline-Activated and Control conditions (which were not presented during the Relearning Phase and correspond to a typical RIF procedure) as well as Relearned-Activated and Control conditions.

The Generation Phase showed the cumulative interference effect typically observed in picture naming procedures using category + stem cues. This interference was chiefly present in the first of three repetitions of the materials. In the Relearning Phase, there was a pattern of retrieval-induced semantic interference in which Activated retrieval was delayed relative to Control, although this pattern did not reach significance. Cumulative interference was observed across all Repetitions in this phase, indicating that generative relearning elicited new interference. In the Final Naming Assessment phase, Baseline-Activated items took significantly longer to name than Baseline-Controls (a RIF effect), as expected. Critically, this pattern of retrieval-induced semantic interference was completely absent when items were generated and refamiliarized ("relearned") following their downregulation. Moreover, Generated-Activated latencies were *not* facilitated relative to their Generated-Controls, indicating the absence of enhanced relearning within a picture naming context. Also contrary to predictions, there was

robust cumulative interference across all Repetitions for Generated conditions, contrasting with the much weaker accumulation of interference in the Baseline conditions.

In sum, stable cumulative interference was observed in all phases of the experiment, demonstrating the utility of using language production tools to illuminate the temporal dynamics of adaptive learning. Critically, I also found that generation and refamiliarization completely overrode the impaired conceptual-lexical access incurred by prior related generation, but relearning was not enhanced for recently punished competitors relative to controls. I now turn to address the commonalities and divergences of the present results from previous research before discussing implications for models of conceptual-lexical access.

Comparison to Other Studies of Relearning following Semantic Interference

The erasure of retrieval-driven interference after relearning replicates the pattern of results from Storm et al. (2008) and Storm & Soares (2022). This is especially notable given that the present design differed from Storm et al. in several regards. First, I adopted an incremental language production perspective in which I assessed how latencies varied across related generations in place of retrieval success/failure in all phases. This methodology provides insight over the opaque measures typically used in memory/RIF designs, which only report aggregate measures. In the current work, the design of each phase comprised an internally structured sequence that allowed the assessment of category member ordinal position and provided a window into the temporal dynamics of retrieval-driven learning and (re)learning. Specifically, the present results show that cumulative interference, as is typically observed in the language production literature, occurs in all phases of the modified retrieval practice paradigm. Critically, while this cumulative interference occurred during the initial downregulation of competitors in the Generation phase, new cumulative interference was also supervenient to any residual

learning in the subsequent two phases. This suggests that memory researchers should assess how accessibility changes across related generation instances in each phase rather than relying on aggregate measures.

A second deviation from previous work is that relearning was implemented through a generation + refamiliarization format rather than the simple refamiliarization/restudy used in past work (Storm et al., 2008; Storm & Soares, 2022; Hulbert & Norman, 2015). I posited that semantic elaboration during generation would result in more robust relearning, even though it poses the challenge of accruing new interference across the Relearning sequence. More specifically, generation entails both the strengthening of selected targets and the downregulation of coactivated competitors, such that net outcomes reflect a delicate balance between two opposing forces. Contrary to predictions, the present work using generative relearning replicated the results found when using non-generative relearning (Storm et al., 2008; Storm & Soares, 2022), such that the two methods elicit equivalent results in this context. It is possible that the interplay of strengthening and weakening cancelled one another out, so to speak, or that Generation may simply play a greater role during the initial downregulation (i.e., retrieval specificity, see Anderson, 2003). Together, these findings suggest that relearning (i.e., erasure of previous downregulation) chiefly requires exposure to the punished competitors and is not modulated by generative processes. I do note that this is only one test of a different relearning procedure, and other variations may prove informative. For example, a Relearning Phase entailing only generation (without refamiliarization) would further clarify the present results. Alternatively, a procedure using latent presentation of past competitors and controls (such as masked priming) would clarify the role of overt comprehension on the restoration of conceptual-lexical access.

The last critical deviation was that picture naming cues were used in the Final Assessment phase instead of category-stem cues. Picture naming utilizes pre-existing conceptual-lexical mappings rather than relying on experiment-specific stimulus pairings, thereby providing a more ecological assessment of conceptual-lexical access. Cumulative interference was observed during both category-stem cue generation and picture naming, suggesting that, at least to some extent, a similar incremental adaptive learning mechanism acts on both mediums. However, while past work using category-stem cueing found marginally better retrieval performance after downregulated representations were re-exposed prior to the Final Assessment (Storm et al., 2008), the present experiment found that picture naming performance was equivalent in Generated-Activated and Generated-Control conditions. The lack of enhanced relearning in this context calls into question the robustness of this phenomenon generally, as well as provides evidence that it may not occur in well-learned conceptual-lexical mappings.

The erasure of interference following generation + refamiliarization in the present work is consistent with Storm et al. (2008) and Storm & Soares (2022). However, it is somewhat *inconsistent* with the marginally significant (behavioral) enhanced relearning effect found by Hulbert & Norman (2015), as well as the neuroimaging evidence of heightened differentiation for previously punished competitors. Why might these results differ? I suggest this divergence is due to the choice of materials. In the present work (and Storm et al.), sets of superordinate category + exemplar pairs served as the materials (e.g., BIRDS– seagull, BIRDS – turkey, etc.), whereas in Hulbert & Norman (2015), the sets comprised individuated exemplar picture + name pairs (e.g., Paxton the Pig, Pryor the Pig, etc.). Thus explicit episodic learning was required to later retrieve the correct name. Notably, all names in a given set shared the same phonological onset (/p/) with each other and with the subordinate category name. In interactive models of

language production, it is posited that selected phonological segments also spread activation back *up* to preceding layers, which in turn heightens the activation of competing *lemmas* with shared segments (e.g., Dell & O'Seaghdha, 1992). Thus when two already coactivated words also share an initial phonological segment, such as /p/, it follows that these words would become especially competitive, and downregulation would be heightened. This is not inherently problematic- there are certainly times in which one must retrieve a given name amongst similar sounding ones. However, it may have incidentally heightened competition in a way that does not occur in category-stem cue generation. In terms of the Nonmonotonic Plasticity Hypothesis, the two different set construction methods may differ on where they fall on the nonmonotonic curve of coactivation (Ritvo et al., 2019). That is, the subordinate categories with shared onsets used in Hulbert and Norman (2015) may have incidentally fallen onto the apex of this curve, resulting in more robust differentiation and relearning than for the superordinate category sets of the RIF and language production literatures.

Aside from comparison to the present results, the choice of materials also has implications for the conceptualization of where adaptive learning occurs. According to Hulbert & Norman (2015), confusable pictures with low frequency names were used to encourage effortful retrieval during their experiment, with the assumption that low-frequency names arbitrarily assigned to highly confusable pictures would be more difficult than category-exemplar pairings. Thus, the authors establish difficulty through competitive episodic binding rather than intrinsic semantic feature overlap. This conceptualization of interference (and enhanced relearning) as an episodic memory phenomenon (see also Ciranni & Shimamura, 1999) contrasts to the conceptualization of semantic interference in the language production literature, in which interference is primarily localized to semantic memory processes. It is worth noting, however,

that the current discourse context impacts accessibility of related representations (e.g., Binder & Morris, 1995; Lucas et al., 1999), such that episodic context may play either an additive or modulating role in retrieval-driven adaptive learning. In support of this idea, recent work has shown the necessity of including the surrounding episodic context in models of lexical access and retrieval. Recall that Norman et al. (2007), which enacts adaptive learning by modulating intraconceptual links, instantiated both a hippocampal and a context layer to link patterns of semantic activation to the surrounding episodic context. The updated incremental learning model of lexical retrieval developed by Oppenheim and Nozari (2024) still focuses on adapting conceptual-lexical links but implements a context layer similar to that used in Norman et al. (2007) in which the activation of certain semantic (thematic) features is dependent on the surrounding context. In this way, both the episodic context and intrinsic featural overlap contribute to adaptive learning processes, and future work should aim to clarify the relative contributions.

Implications for Models of Conceptual-Lexical Retrieval

To date, no model of language production can account for enhanced relearning of conceptual-lexical access. Specifically, most models predict that generating previously downregulated words would restrengthen conceptual-lexical links back to their original strength, but they would *not* predict that re-exposure would enhance accessibility for these items more than never-punished controls (Oppenheim et al., 2010; Roelofs, 2018; Howard et al., 2006; Melinger and Abdel Rahman, 2019). As previously discussed, the Oppenheim et al. (2010) model of incremental learning in language production only weakens conceptual-lexical links for the features shared by the target and competitors, and so the unshared features of the competitor are left untouched. This contrasts with the mechanisms proposed by differentiation accounts

(Ritvo et al., 2019). Thus, a key test of both the sufficiency of current language models and the validity of accounts like the Nonmonotonic Plasticity Hypothesis was to examine the enhanced relearning of previously downregulated words. If enhanced relearning were observed in a language production context, the current models could be deemed insufficient and new options would need to be explored. One possible test would be to see if including strengthening between unshared competitor features alongside the weakening of links to shared features could account for current behavioral findings.

The present experiment did not find enhanced relearning in conceptual-lexical access. Two interpretations could reasonably be drawn from this null finding: 1) enhanced relearning is not a robust behavioral phenomenon, or, 2) it does not apply in a word production context due to the well-established connectivity of interrelated conceptual-lexical representations. The present data do not make it possible to differentiate the two possibilities with any certainty, but it is reasonable to question the applicability of long-term enhanced relearning within a production context. In typical speaking, conceptual-lexical retrieval and selection is remarkably fluent, and we are constantly retrieving and producing words that are semantically related to one another. The pervasive nature of this semantically related retrieval can be difficult to connect to the highly contrived retrieval paradigms of memory experiments. For example, in previous procedures using subordinate category-name pairs, the arbitrary pairings of names and specific photos must be explicitly learned (Hulbert & Norman, 2015). In this task-specific context, the system may downregulate (and differentiate) items to a fairly extreme degree. In contrast, although readily observable through sensitive latency measures, the downregulation elicited within a word production context may be lesser in magnitude, assuming that it is highly likely one will need to later produce a downregulated word. Moreover, given the nature of the lexicon

and the rapid pace of typical speaking patterns, hyper accessibility of related representations elicited by enhanced relearning processes would result in a high degree of production errors in an already competitive system.

However, there is some preliminary evidence that some form of enhanced relearning may occur within a damaged lexicosemantic system. Specifically, Patra et al. (2022) explored the role of previous competition in promoting lexical retrieval and production in aphasic patients. In an initial training phase, participants engaged in cyclic picture naming (in which small sets of pictures are repeatedly named across several cycles), with pictures presented in either related (i.e., a competitive context) or unrelated sets (a noncompetitive context). The next day, participants completed an assessment phase of picture naming containing the same items. while naming accuracy was significantly worse for competitive contexts in the initial training phase, there was no difference between the two contexts in the final assessment. Critically, however, subsequent analyses indicated that higher item-to-set semantic similarity was associated with heightened naming accuracy in the final test. That is, while semantic competition may impair naming during initial retrieval, the effort expended within a competitive naming context may actually drive greater strengthening upon regeneration. While compelling, it is worth noting that these findings only reflect adaptive learning in aphasiac speakers, and the evidence in favor of enhanced accessibility following increased competition is somewhat weak. Thus future work should endeavor to clarify whether the results of the experiment reported here reflect methodological limitations or if enhanced relearning is not a component of the adaptive learning processes in neurotypical speakers.

Conclusion

The findings reported here provide preliminary evidence that generative retrieval completely ameliorates past interference, even as new cumulative interference accrues during the regenerative process. However, there was no enhanced relearning for recently downregulated semantic competitors. In addition, the present experiment provides another compelling case for assuming an integrated view of conceptual-lexical retrieval by using language production methodologies to dynamically explore how each related retrieval instance shapes the accessibility of known words (Hambric & O'Séaghdha, under review). I observed cumulative interference across ordinal positions in all phases of the experiment, underscoring the overlap between memory retrieval and language production measures of semantic interference and providing a window into the temporal dynamics of adaptive (re)learning. Critically, I also observed the typical pattern of impaired access to Activated items (relative to Control) in the Baseline condition, but Activated items that were generated and refamiliarized prior to the final assessment did not differ from generated Controls. Paired with the weak behavioral evidence of enhanced relearning in other semantic memory contexts (Storm et al., 2008), these results suggest that language production and memory researchers may be investigating different aspects of the same semantic interference phenomena, but enhanced relearning of downregulated semantic competitors may only occur in a limited set of circumstances outside of a typical speaking context.

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Declaration of Interest Statement

I report no conflict of interest.

Data Availability Statement

Materials, by-trial data, and analysis code are openly available on OSF.

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Component 3: *Durability and Locus of Semantic Interference*

Abstract

Generation from memory can hinder later access to related conceptual-lexical representations. This *semantic interference* is generally understood to be insensitive to time, but to date there has been little direct investigation of this claim. Moreover, since generation entails both conceptual and lexical retrieval, it is possible that interference arises at either or both levels of representation. The present set of experiments sought to examine the durability of interference following related picture name generation and to clarify the roles of conceptual versus conceptual-lexical processing in semantic interference. Two experiments (3A and 3B) used a straightforward picture naming procedure in both Generation and Assessment Phases. To explore the longevity of interference and the possible role of sleep-based consolidation processes, the final assessment phase took place either 15-min or the day after the Generation Phase. Two other experiments (3C and 3D) focused on the issue of locus, namely the respective roles of conceptual versus conceptual-lexical learning. I replaced the picture naming Generation Phase of the previous experiments with a pre-lexical picture matching task. This phase was followed by an assessment phase that engaged either conceptual-lexical (picture naming, 3C) or pre-lexical processing (picture matching, 3D). In Experiments 3A and 3B, I did not observe significant retrieval-induced semantic interference in latencies, even though there were significantly more errors in the Activated condition (compared to controls) when the assessment occurred the next day. This is surprising given the long-term effects observed after related category-stem cued generation in the prior dissertation components, and could suggest attenuated learning in the initial Generation Phase. In Experiments 3C and 3D, I observed cumulative facilitation in the

initial picture matching sequences. In 3C, this contrasted with the cumulative interference observed in the following picture naming phase. In both experiments, there was no effect of prior related picture matching in the assessment phase. Together, these results call for more investigations into the claim of temporal insensitivity and suggest that lexical generation may be necessary to elicit semantic interference effects.

Introduction

Two central factors in integrating the current literatures of semantic interference are establishing the durability of interference and whether it arises primarily in conceptual representations or in links to lexical concepts or lemmas. The results of the prior two components provide some preliminary evidence. In Component 1, significant retrieval-induced semantic interference was observed after a 15-minute retention interval, indicating that the adaptive learning that took place during the category-stem cued Generation Phase survived the temporal lag. In Component 2, the expected retrieval-induced interference was not significant in the Relearning Phase, but the effect was significant for Baseline items in the following Assessment Phase. Together, these results provide evidence that the same incremental adjustment to access occurs in both category-stem cued generation and picture name generation, that the interference that accrues in one medium transfers to the other, and that interference is fairly persistent. How do these results thus inform the key questions of durability and locus of interference?

Regarding durability, the current results suggest that retrieval-induced semantic interference is insensitive to time, as proposed by both Oppenheim et al. (2010) and Norman et al. (2007). However, the evidence thus far only comes from related category-stem generation, and the longevity of interference elicited by other (arguably more naturalistic) forms of conceptual-lexical retrieval remains underexplored (but see Schnur, 2014). Regarding the issue of locus, among the possible interpretations of the current findings, there are two primary possibilities. One, incremental conceptual-lexical learning (i.e., modulation to conceptual-lexical links) contributes to, or may even be fully responsible for, the degraded access to semantic competitors. Or two, cumulative interference in language production actually originates from adaptations within conceptual representations themselves (e.g., Norman et al., 2007). Thus the

third component of this dissertation is comprised of a series of experiments designed to examine the durability of interference and the relative (and possibly combined) contributions of conceptual and conceptual-lexical modulations in retrieval-driven semantic interference.

As discussed previously (see *Semantic Interference in Language Production*), while most researchers agree that some form of long-term adaptation is necessary to account for cumulative semantic interference, there is still disagreement about the exact nature of this mechanism (Damian & Als, 2005; Oppenheim et al., 2010; Howard et al., 2006; Abdel Rahman & Melinger, 2018; Belke, 2013). Specifically, while some researchers posit that learning acts on conceptual-lexical links (Howard et al., 2006; Oppenheim et al., 2010), others argue that the long-term effect originates at a pre-lexical, conceptual locus. Specifically, Belke (2013) argues that it is the links between conceptual features and *lexical concepts* that are modulated. These lexical concepts are somewhat of a misnomer in that they are proposed to be a conceptual precursor to *lemmas* and roughly correspond to a single node that captures collections of conceptual features without any lexical information (e.g., Roelofs, 2018; Vigliocco et al., 2004; Belke, 2013). Note that this account is distinct from the conceptual adaptive learning of Norman et al. (2007). In Norman et al. (2007), adaptive learning is implemented by adapting the connective weights between semantic features within concepts themselves, whereas Belke (2013) posits that learning acts on the links between features and lexical concepts (Belke, 2013). This is similar but separate from the account of Oppenheim et al. (2010), which entails adaptations to the links between conceptual features and lemmas. Whether or not the inclusion of lexical concepts meaningfully contributes to accounts of conceptual-lexical retrieval remains an open question. It is possible lexical concepts merely function as a conjunctive level between features and lemmas that is not subjected to modulation. However, the idea that it is conceptual, and not conceptual-lexical

adaptive learning that drives semantic interference remains a compelling possibility. In support of this view, a recent study by Döring et al. (2022) found that words of varying morphology elicited the same amount of cumulative semantic interference. The authors suggest that since interference is not affected by morphological complexity, this indicates that it is primarily mediated by pre-lexical, conceptual processing. In addition, they found that facilitation observed in a categorization task predicted the amount of cumulative interference in continuous picture naming, which they argue suggests a conceptual origin for the two tasks (Döring et al., 2022). They thus adopt a similar view to that of Belke (2013) and propose that semantic interference may be best characterized as conceptual-level adaptive learning that modulates the connectivity between semantic features and lexical concepts.

Other work that does not discriminate between lexical concepts and lemmas addresses the idea that adaptation within semantic memory may be the driver of interference. Wei and Schnur (2016) investigate the locus of semantic interference in comprehension by comparing the interference observed in a word-picture versus a picture-picture matching task. Based on a paradigm developed by Campanella and Shallice (2011), participants were presented with a central word or picture (e.g. PANDA) and a surround of four pictures (e.g., bamboo, yarn, banana, honey), and asked to select the picture in the array that is associatively related to the central cue (PANDA – bamboo), see Figure 6. Wei and Schnur (2016) proposed that accessing the semantic information of the central cue would latently activate taxonomic relatives, and these competing items must be suppressed to access the correct thematic information. They thus predicted that matching would be hindered when successive cues were taxonomically related. To manipulate semantic competition, the central cues within testing blocks were thus either taxonomically related (PANDA, KITTEN) or unrelated (NOSE, KITTEN) to the other cues in

the block, creating related and unrelated sequences. Each cue was presented over multiple cycles, thereby implementing a type of cyclic naming. Wei and Schnur (2016) also predicted that interference in related blocks would accumulate over cyclic repetitions, as predicted by Oppenheim et al. (2010). For the present purposes, the crucial manipulation was whether the central cue was presented as a printed word or as a picture. Wei and Schnur (2016) proposed that since the picture cue condition does not necessitate lexical processing, interference in this condition would support a conceptual rather than a lexical basis for semantic interference. Note that participants named the central cue pictures in conjunction with the matching task in this experiment. However, the authors stated that since a post-hoc analysis did not find any effect of lexical frequency, which reliably modulates lexical effects, the results do not reflect the engagement of lexical processing.

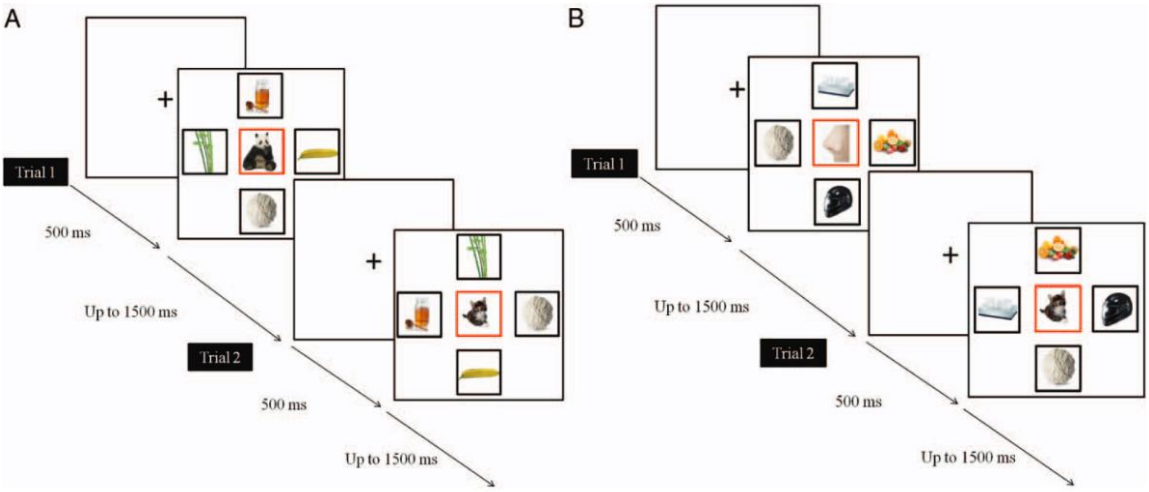

Figure 6. Figure 1 from Wei & Schnur (2016). A) Related picture cue block. B) Unrelated picture cue block. The word cue blocks were identical except that the central pictures were replaced with corresponding printed words. Each block contained 4 central probes surrounded by the same 4 pictures, and each cue was matched across four repeated cycles.

Consistent with predictions, it took longer to match pictures in related compared to unrelated blocks, regardless of whether the cues were pictures or words. At odds with some findings from our own work (O'Séaghdha et al., in prep), a cyclic cumulative interference effect was observed, with the difference between the related and unrelated blocks increasing over cycles (Wei and Schnur, 2016). Note that this is different from the cumulative interference effect in continuous naming, which modulates the accessibility of related, non-target semantic relatives. Rather, in this experiment, the increase in interference was across presentation cycles for the same items. The cyclic naming design has often been criticized for relying on top-down control processes (see Hambric & O'Séaghdha, 2023), so these results may reflect overt strategies in addition to endogenous learning processes.

The authors concluded that the equivalent incremental learning observed in both tasks suggests that semantic interference reflects the prelexical processing shared by both tasks, rather than adaptations to conceptual-lexical links (Wei & Schnur, 2016; see Oppenheim et al., 2010). They suggested that current accounts are insufficient, and a similar incremental learning mechanism to those developed by Howard et al. (2006) and Oppenheim et al. (2010) must be present within semantic memory itself. Specifically, they suggested that the "hub and spoke" model developed by Rogers et al. (2004) could readily be updated to include modifiable links between distributed semantic features and amodal conceptual representations. For the present purposes, their findings are mostly in line with Belke (2013) in that they suggest that pre-lexical incremental learning contributes to (or may be fully responsible for) retrieval-induced semantic interference. Experiments in this Component aim to provide further evidence concerning pre-lexical versus lexically based incremental learning by comparing learning in picture naming and picture matching procedures.

In addition to examining the locus of cumulative interference, Component 3 will also provide benchmark data on the longevity of retrieval-induced semantic interference. Recall that Oppenheim et al. (2010) posited that the conceptual-lexical learning underlying cumulative interference is insensitive to time. To date, this proposition remains underexplored in language production (but see Schnur, 2014). Given that Component 1 established that retrieval-induced forgetting and cumulative interference reflect the same underlying learning mechanism, I suggest that the retrieval-induced forgetting literature may provide relevant evidence on the issue of longevity. Not only is classic retrieval-induced forgetting observed after a 15-20 minute retention interval (a significant temporal lag relative to typical language production studies), but other work has shown that hindered category-stem completion of semantic competitors was observed up to *one week* after the initial Generation Phase (Storm et al., 2012; Tandoh & Naja, 2007).

There is also evidence for the role of sleep in the perseverance of retrieval-induced semantic interference. For example, the earlier reviewed work by Abel and Bäuml (2012) showed that RIF was only visible after a 12 hour retention interval if sleep had occurred during the timeframe (see *Time Course* section of Introduction). They suggested that sleep is critical due to the occurrence of consolidation processes. During consolidation, memories are thought to be translated into more durable traces. Thus when adaptive learning is followed by a period of deep sleep, newly modified structures within the semantic network may be consolidated and preserved across significant retention intervals (Abel & Bäuml, 2012).

Sleep has also been proposed to play a role in long-term lexical adaptation, especially when acquiring the meaning of new words or learning novel meanings of known words (e.g., Gaskell et al., 2019; Hulme & Rodd, 2023). For example, Dumay and Gaskell (2007) and Dumay and Gaskell (2012) showed that sleep is necessary to fully integrate new vocabulary

words into the lexicon (as indexed by their endogenous competition during auditory word recognition). Specifically, Dumay and Gaskell (2007) suggested that sleep may allow for recently acquired words to be consolidated in long-term cortical stores, which may thus indicate that sleep plays a role in preserving the recent strengthening of the links between the lexical representations of new vocabulary words and the corresponding conceptual features.

The experiments in Component 3 explored the longevity and locus of the learning that underlies retrieval-induced semantic interference. Following Wei and Schnur (2016), these experiments compared the durability of interference that originates from primarily conceptual-lexical processes to interference from primarily conceptual processes. Specifically, Experiments 3A and 3B used generative picture naming in both Generation and Assessment Phases and assessed durability by conducting the final Assessment Phase either 15-minutes or the day after the Generation Phase. The initial plan for the four sub-experiments of Component 3 was to conduct a 2x2 set of experiments in which both the learning task and the retention interval length were manipulated. This would then allow for an omnibus analysis as well as individual analyses for each experiment. In Components 3C and 3D, a novel continuous variation of the pre-lexical picture matching task was used during the Learning Phase, with the assumption that if conceptually based adaptive learning drives interference, cumulative interference would be observed in this phase (as in Wei & Schnur, 2016). Before the key experiments, I conducted a Pilot Study to benchmark the new picture matching task. To preview the results, I unexpectedly observed cumulative facilitation rather than interference. In light of these findings, I adjusted the plans for Experiments 3C and 3D. Specifically, I dropped the durability manipulation and instead examined how the cumulative facilitation that occurred during picture matching would affect subsequent access to related representations when conceptual-lexical processing was or was not

engaged during the Final Assessment. In Experiments 3C and 3D, the pre-lexical picture matching task was used in the Learning Phase, and the Final Assessment Phase engaged either primarily conceptual-lexical (picture naming, 3C) or conceptual (picture matching, 3D) processes. Thus in addition to addressing the claim that interference is insensitive to time, this component also addressed the question of where semantic interference originates.

Picture Matching Pilot Experiment

The first step in this multi-experiment component was to choose a pre-lexical task that would elicit cumulative interference but that would not require lexical processing. By using such a task, I would be able to compare the pattern of interference to that observed for tasks requiring conceptual-lexical processing. If a similar pattern of cumulative interference were observed, this would suggest that the common level of processing (conceptual level) is the driver of interference. The task I chose to implement was a variation of the picture-picture matching task (Wei & Schnur, 2016; Biegler et al., 2008; see discussion above). This variation followed the by-trial procedure of Wei & Schnur (2016), but the design differed in two key regards. First, rather than adopting the cycling design of Wei & Schnur (2016), I instead intermixed the related trials across a continuous sequence in the same way as in previous experiments, such that cumulative interference across related trials could be assessed. Second, rather than having the central cue be taxonomically related across trials, I used the inverse format originally implemented as a word-picture matching task by Biegler et al. (2008). In Biegler et al. (2008; Experiment 3), six pictures from the same taxonomic category were presented on the screen at once, and participants were instructed to select the picture that was most closely associated with an auditorily presented cue word. The options in each block were all taxonomically related or were unrelated. This format thus directly activates the relevant cohort of category members on top of that established by

endogenous spreading activation processes. In addition, this format also entails the selection of taxonomically related targets across trials, the same targets that are retrieved in picture naming tasks. As in Wei & Schnur (2016), Biegler et al. (2008) found that selection times were significantly greater in semantically related blocks compared to unrelated blocks. Latencies decreased across the block, but this was attributed to task practice. However, as shown by the following pilot experiment, it is possible that this effect actually reflected long term conceptual priming.

The present experiment implemented a similar by-trial logic with a picture-picture format. Four surrounding pictures were members of a taxonomically related set, and the central cue picture was an associate of one of the surrounding items. Thus on each trial, the participant had to click on the surrounding picture that was most closely associated with the central cue picture. The next related trial (in the next quartile) entailed the presentation of the same set of four taxonomically related pictures with a new cue that was associatively related to one of the remaining unmatched items. What follows is the pilot experiment conducted to benchmark this picture matching procedure. I predicted cumulative interference over related target ordinal positions, even though the matching task does not necessitate lexical retrieval or selection. If confirmed, this pilot experiment would support a conceptual origin of retrieval-induced semantic interference.

Method

Participants

24 participants were recruited from Lehigh University in return for class credit in an introductory psychology course.

Materials and Apparatus

Ten groups of eight taxonomically related items (80), and 80 item-specific associates, were selected using the Bank of Standardized Stimuli (Brodeur et al., 2010; Brodeur et al., 2014), materials from Wei & Schnur (2016), and experimenter discretion (see Appendix C). The relatedness of items in each taxonomic group and associate relatedness of each cue were established using the normative data from the Bank of Standardized Stimuli (Brodeur et al., 2010; Brodeur et al., 2014), the Nelson USF norms (Nelson et al., 2004), and experimenter discretion. A full list of the materials and the selection criteria can be found in Appendix X. Care was taken to ensure that each associate cue was not taxonomically related nor strongly associated with another target. Additional frequency data were acquired from the LexOPS database to ensure selected stimuli were as equivalent as possible (Taylor et al., 2020). Associate cue pictures were presented centrally, and the four picture options were presented in an array surrounding the central cue. All pictures were sized to approximately 4 x 4 inches (Brodeur et al., 2014), appeared directly above, below, to the left, and to the right of the central cue. Text was presented in 14-point Corsolas font.

The experiment was programmed using E-Prime 3.0 and was conducted using a Dell OptiPlex 7020 computer with a 1908FPt 75 DPI monitor with a refresh rate of 80 Hz. Participants were seated approximately 16 inches from the screen.

Design

The experiment comprised one overarching phase internally divided into four quartiles. In order to have only a single category item per quartile, only half of the items from each category were presented (40). The specific half presented was counterbalanced across two experimental versions. One item from each category was randomly assigned as the target in each

quartile. The order of presentation within each quartile was randomized, and the order of quartiles was counterbalanced across participants. In addition, the specific location of each picture in the array was balanced in a Latin Square across Ordinal Positions so that the same groups of surround pictures appeared in each quartile, but they always appeared in different spatial configurations. Thus the primary factor of interest was Ordinal Position, which was used to assess the presence of cumulative interference.

Procedure

Familiarization

Following standard practice in both the memory and language production literatures, participants were first introduced to the materials. All items (both central cues and possible targets) were presented with both their picture and name. On each trial, a fixation cross appeared for 200 ms, followed by the presentation of a picture with the corresponding name below it for 1500 ms. To ensure that the information was registered, participants read each picture name aloud. No data were collected.

Picture Matching Phase

Participants were told they would be completing a picture matching task. They were instructed that on each trial, a central picture would appear (with a green border) as well as four surrounding pictures. On each trial, they should use the mouse to click on the surrounding picture that was most closely associated with the central picture as quickly and accurately as possible. Participants completed a practice trial before beginning the experimental sequence. To prevent overt strategizing, participants were not told how many pictures they would be matching, nor how many central associates were associated with each target. On each trial, a fixation cross appeared for 200ms followed by the simultaneous presentation of the central picture cue and

surrounding picture array. The display lasted 8 seconds or until a mouse click response was registered. The next trial began 1000 ms after the conclusion of the previous. Click onset latencies and accuracy were recorded on each trial.

Results

All trials with a response time of less than 250 ms were considered erroneous and dropped from the analysis. The picture matching error rate was low (8.1%), and errors were evenly distributed over quartiles, (N_{Q1}=18, N_{Q2}=20, N_{Q3}=20, N_{Q4}=20). Incorrect trials were dropped from the analysis. A linear mixed model analysis was conducted as in the previously reported experiments. Ordinal Position was specified as the solitary fixed factor, and random intercepts were included for both participants and items.

There was a marginal effect of Ordinal Position (F (3, 798) = 2.23, p =.08), but, as can be seen in Figure 7, the effect was in the opposite direction than predicted. That is, matching times tended to *decrease* over Ordinal Positions, thus displaying cumulative *facilitation* rather than interference.

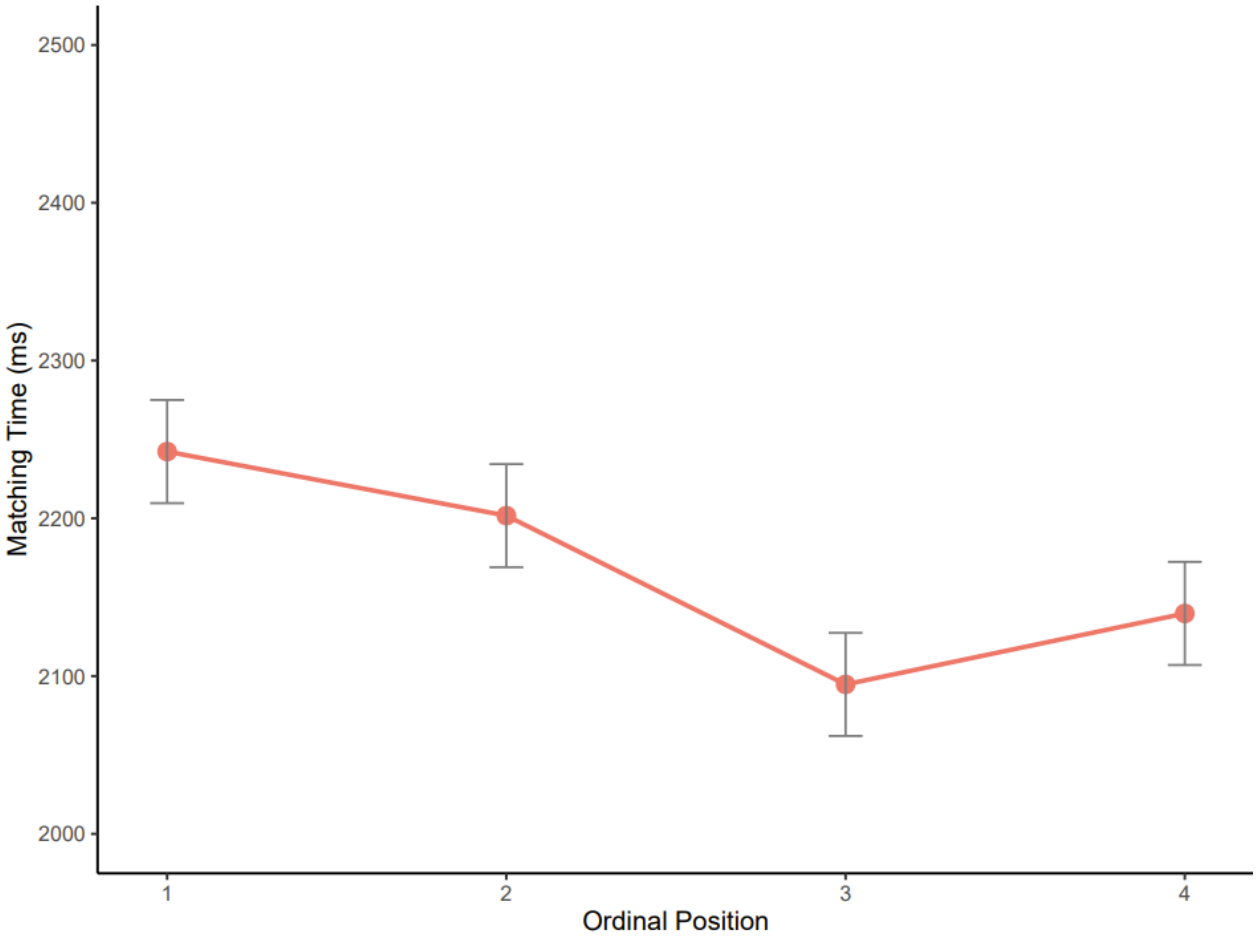

Figure 7. Pilot Study: Cumulative facilitation over Ordinal Positions in Picture-Picture matching.

Interim Discussion

The novel picture matching paradigm reported here sought to establish cumulative interference in a task that primarily engaged pre-lexical, conceptual processing. This was to serve as a basis for comparison with the cumulative interference observed in generative picture naming tasks and aid in disentangling the roles of conceptual versus conceptual-lexical adaptive learning. Surprisingly, I found that iteratively matching taxonomically related pictures across a structured continuous sequence was associated with cumulative *facilitation* across ordinal

positions. The effect was only marginal, but this may be due to the modest sample size of the pilot study. This finding is opposite to initial predictions of cumulative interference. Why might this be?

Wei & Schnur (2016) posited that bringing to mind the relevant associative information of a given target entails "selecting" that representation over coactivated taxonomic relatives. These competing items are then downregulated, which in turn leads to interference. Based on this reasoning and the evidence from the cyclic version of the picture matching task, I thus predicted interference over ordinal positions in the matching task. However, the present finding of cumulative facilitation suggests that this account is not correct. I also note that the present results may also differ from Wei & Schnur (2016) due to methodological differences. Recall that in Wei & Schnur (2016), the central cues, rather than the selected targets, were taxonomically related (within a given block). In addition, although the matching task did not necessitate production, participants were nevertheless asked to generate the names of the (taxonomically related) central picture cues while matching. The authors claimed that since a post-hoc analysis found that lexical frequency was unassociated with the degree of interference, lexical processes were unlikely to have played a role in cumulative interference. In light of the current results this assumption may be incorrect, and it may be that lexical generation processes were responsible for downregulatory adaptations.

A re-review of the relevant literature revealed that, in comparison to other work on long-term conceptual learning, the interference observed by Wei & Schnur (2016) was quite anomalous. Other work (e.g., Tse & Neely, 2007; Hughes & Whittlesea, 2003; Was et al., 2019; Woltz et al., 2010) has found that conceptual retrieval facilitates category judgments of new related exemplars relative to unrelated controls. For example, Was et al. (2019) conducted a

long-term priming study in which participants were first primed by trials asking them to make either exemplar comparison (e.g., "EAGLES are like…canaries OR feathers) or feature-based judgements (e.g., SPANIELS have…owners OR hounds). Then, after a set of filler trials, participants were asked to make similar judgments for new exemplars and new features. The key manipulation was if these new items were related to previously encountered exemplars/features (e.g., BLUE JAYS are like…hawks OR nests) or unrelated (e.g., ROSES have…petals OR orchids). Was et al. (2019) found that judging items semantically related to previously encountered items was significantly faster and more accurate than unrelated controls, regardless of if the judgement type was congruent with the previous operation (i.e., another exemplar comparison or feature judgment). The authors suggest that these results indicate that repeatedly activating sets of conceptual features incrementally strengthens their coactivation, thus facilitating later judgment of items sharing the same features (see also Becker et al., 1997). Thus, in this task where one must retrieve taxonomic information but no overt generation is required, past conceptual activation facilitates subsequent categorization.

This unexpected finding is inextricably tied to the broader issue of locus, and the extensive work by Belke (2013) is extremely relevant to the present issue. Specifically, Belke (2013) argued that it is critical to differentiate between the *origin* and *locus* of semantic interference. She proposed that the origin of semantic interference is conceptual-level adaptive learning, but the downstream effect of this learning depends on whether lexical generation is engaged.

In her working model (which has yet to be computationally implemented), an adaptive learning mechanism adapts the links between shared features and coactivated lexical concepts. These lexical concepts feed directly (in a one-to-one fashion) into lemmas. When performing

tasks such as category judgment (which does not require lexical access), one must use the automatically activated taxonomic features to make the correct category judgment. That is, the target response is a given category, which is inherently shared by taxonomic relatives. Belke (2013) posits that the links to categorically congruent features are strengthened for the given target as well as all coactivated lexical concepts (albeit to a lesser extent). This strengthening then facilitates subsequent category judgment for categorically related items.

This supposition is in line with the present results. In the current matching task, coactivating the same set of taxonomically related features might strengthen their coactivation. Following Belke (2013), this could happen by strengthening the links between shared features and all coactivated lexical concepts. For example, when participants matched the associative cue *bone* to the target *dog,* the conceptual features of *fur*, *tail,* and *chews bones* would be coactivated. A learning mechanism would then strengthen the links between *fur*, *tail, chews bones* and the target *dog*, as well as the connections between *fur, tail,* and the coactivated category member *cat*. When the associative cue *yarn* is then presented on the next related trial, the associative feature *plays with yarn* is activated. This weakly activates the concept *cat* as well as its connected features *fur* and *tail*. Since the connections to *fur* and *tail* were recently strengthened, the concept *cat* more quickly reaches the activation threshold for target selection.

This process is turned on its head when lexical generation is required. According to Belke (2013), when a picture must be named, activating semantic features results in the coactivation of semantically related lexical concepts. However, now the task is to generate a particular name, such that a lexical concept that represents a single, identifying collection of features must be selected. The links between the target features and the target lexical concept are strengthened, while the links between the shared features and competitors are weakened (similar to Oppenheim

et al., 2010). This then results in hindered access to the previously downregulated lexical concepts when they must be named later in the sequence. this process sounds quite similar to what is proposed to occur in the current picture matching task. That is, unlike the category judgement task used by Belke (2013), the picture matching task required the selection of a single target based on item-specific associative information, rather than indicating a given category that was congruent across taxonomic relations. Thus, as it is currently implemented, her working model could not account for the present cumulative facilitation effect in picture matching.

However, Belke (2013) also has some relevant predictions regarding the effect of prior categorization on later retrieval. Although picture matching may be dissimilar to categorization tasks for the reasons described above, I suggest that the logic may nevertheless have some interesting implications for the downstream effects of picture matching. If categorization-based learning strengthens the feature-concept links amongst coactivated items, it follows that, in a subsequent picture naming task, semantic competitors would be more coactive when naming a taxonomic relative. In a generative context where only a single name can be produced at any given time, this coactivation would induce interference. Specifically, Belke (2013) predicts that facilitation accumulated in a nongenerative task may "flip" to interference when generation is suddenly required (see Experiment 5). I note that this hypothesis depends on lexical selection being a competitive process (as in Levelt et al., 1999), which is inconsistent with the conclusions of Oppenheim et al. (2010). If one instead assumes that selection is not competitive, the heightened coactivation of taxonomic relatives would increase the accumulation of interference over related generations (i.e., ordinal positions).

Taken together, it follows that if conceptual-level adaptation is the source of interference, and if interference only occurs when conceptual-lexical retrieval is required, then long-term

conceptual facilitation should turn into heightened interference for related items when a generative task is introduced. In addition, if only conceptual-level processes are engaged, past conceptual activation should facilitate processing of semantic relatives compared to unrelated controls.

As previewed above, I adjusted the experimental plan based on these hypotheses The initial plan had been to conduct a set of symmetrical studies in which Experiments 3A and 3B used generative picture naming as a proxy for conceptual-lexical adaptive learning and the issue of durability was explored by having the Final Assessment Phase occur 15-minutes after the Generation Phase or the day after (i.e., including nocturnal sleep). In contrast, Experiments 3C and 3D were to use the pre-lexical picture matching task to elicit conceptual adaptive learning, and the retention intervals and final assessment task (picture naming) were to be identical. However, given the unexpected matching facilitation effect, symmetry in the durability manipulation was no longer of primary concern. In Experiment 3C, I sought to replicate the finding of long term conceptual facilitation in the Learning Phase. I posited that the strengthened coactivation of categorically related items would actually induce heightened interference for related Activated items (relative to Controls) when they must be generated at final test. Following the results of this study, I decided to test the inverse assumption that cumulative facilitation in the Learning Phase would enhance subsequent picture matching performance for semantically related pictures relative to control. That is, the latter experiment sought to investigate if, in a non-generative context across phases, prior conceptual activation would result in long term facilitation. Thus, while the pilot results show that continuous picture matching elicits cumulative facilitation, Experiments 3C and 3D will use the downstream consequences of this facilitation to illuminate the locus of the adaptive learning processes underlying interference.

Component 3 Experiments

This component investigated the durability and origin of retrieval-driven semantic interference. There were four total sub-experiments, two of which elicited long-term learning through a conceptual-lexical (Picture Naming) task and two that used a pre-lexical task (Picture Matching). In the Picture Naming experiments, participants completed a phase of generative picture naming, a retention interval, and a final phase of picture naming containing the usual Control and Activated (items related to previously named pictures) conditions. Critically, by having an unrelated Control condition, one can see if the cumulative interference that accrued for items in the Generation Phase "continued on" to related Activated items in the final phase. In order to explore the issue of durability and the role of sleep-based consolidation, the retention interval was varied across experiments. A full-fledged investigation into the roles of time and sleep would ideally entail a number of equivalent diurnal and nocturnal conditions, but the present experiments were constrained by practical considerations. Thus, the retention interval was varied between subjects to last either 15 minutes (3A) or overnight (3B).

In the final two sub-experiments (3C and 3D), participants completed a phase of non-generative Picture Matching during the initial Learning Phase. In Experiment 3C, the goal was to assess the claim that strengthened coactivation of taxonomically related items would induce interference for related items when individual picture names must be generated. The Learning Phase was thus followed by a 15-minute retention interval and a Final Assessment Phase entailing continuous picture naming. Experiment 3D assessed the opposite "control" assumption that cumulative facilitation observed in the Learning Phase would persist in a non-generative context (i.e., a subsequent phase of picture matching), such that pictures related to those previously matched would be matched more quickly than unrelated controls. The Learning Phase

was thus followed by a 15-minute retention interval and a Final Assessment Phase entailing continuous picture matching. These designs, which integrate the structure of a continuous naming task with the multiphase procedure used in the RIF literature, allowed me to investigate how pre-lexical (Picture Matching) versus conceptual-lexical (Picture Naming) adaptive learning affects subsequent semantic access. The predictions will be detailed in the introductions to each experiment.

Experiment 3A: Picture Naming to Picture Naming with 15 Minute Retention Interval

This experiment is close to a replication of the first experiment reported in this dissertation with a few key exceptions. During the Generation Phase, participants generated picture names from memory in response to picture cues rather than category + stem cues. Critically, given that we observed the same cumulative interference for category + stem cues as is typically observed for pictures, and category-stem generation affected later related picture naming, I concluded that the processing demands (and recruited adaptive learning mechanisms) were quite similar. I thus predicted that we would observe the typical cumulative interference in the Generation Phase and that I would again observe an overall cost to the Activated condition relative to Control in the Final Assessment Phase. In addition, since the prior experiments demonstrated that cumulative interference was largely absent by the second repetition of the Generation Phase and I desired to more closely follow the typical continuous picture naming paradigm, I only used a single pass through the materials during the Generation Phase. In addition, I also chose to not include filler items or present category cues prior to picture targets. Both of these changes were implemented so that this experiment would provide a "pure" test of the longevity of cumulative interference under typical continuous naming task conditions and rule out alternative interpretations of previous findings. Specifically, the use of category cues in

the previous components could plausibly raise questions about the role of overt, overlapping category labels in retrieval-induced semantic interference.

Method

Participants and Power Considerations

I again estimated the appropriate power using the guidelines proposed by Brysbaert & Stevens (2018). Given that there were 20 target trials in each condition of the final picture naming phase, 80 participants were needed to provide up to 1600 observations per condition. They were recruited from Lehigh University in return for class credit in an introductory psychology course. Due to equipment malfunction, 1 participant was dropped from the analyses, resulting in a final N=79.

Materials and Apparatus

The materials were the same ten groups of eight taxonomically related items as those used in the pilot experiment, see Appendix C.

Design

The experiment comprised four sub procedures that mirrored the designs of the previous components. This included an initial familiarization procedure, a Generation Phase, a filler task, and a Final Assessment Phase. The two critical phases comprised two distinct but linked designs (see below). Assignment of categories to each condition and counterbalancing procedures were conducted as in the previous components.

Generation Phase

This phase comprised an abbreviated version of a typical continuous naming task (e.g., Howard et al., 2006). Participants underwent generative picture naming for half (4) of the items from half (5) of the available categories. One item from each category was presented in each of

four quartiles, thus distributing related items evenly. The order of quartiles was balanced across participants via a Latin Square, and items were randomly presented within quartiles. This sequence was presented in a single pass. In this phase, the key variable was the within-subject factor of Ordinal Position.

Final Assessment Phase

In this phase, pictures corresponding to items in the Activated and Control conditions were presented in a continuous stream. As in the Generation phase, one item from each Activated and Control category was randomly assigned to each quartile. The order of presentation within each quartile was randomized, and the order of quartiles was counterbalanced across participants. Immediate repetitions from the same category were not allowed, so there was a minimum lag of 2 and a maximum lag of 16 between members of the same category. Thus, there were two within-subject factors: Memory Condition (Activated versus Control) and Ordinal Position (1-4).

Procedure

The experiment comprised four separate procedures (see Figure 1).

Familiarization

Following standard practice in both the memory and language production literatures, participants were first introduced to the materials. They were told that they would be naming a series of everyday objects and that they would be using the information in subsequent tasks. All pictures used in later phases were presented with their name in a randomized sequence.

On each trial, a fixation cross appeared for 200 ms, followed by the presentation of a picture with its name below it for 1500 ms. To ensure that the information was registered,

participants read each picture name aloud. The experimenter provided feedback on standard pronunciation on the few occasions where it was necessary. No data were collected.

Generation Phase

In this phase, participants were instructed that they would be naming pictures of everyday objects, and that they should try to say each picture name as quickly and accurately as possible. They named 20 target pictures in one continuous sequence internally segmented into quartiles (see Design). On each trial, a fixation cross was presented for 200 ms. The target picture (without label) was then presented for up to 1500 ms or until a naming response was registered. A tone sounded and a "too slow" message appeared for 200 ms if the time limit was exceeded. Another trial began 1000 ms after the previous one.

Filler Task

Participants worked on a printed medium difficulty level sudoku puzzle for 15 minutes. They were instructed to try to complete the puzzle to the best of their ability, but that there would be no formal assessment of their sudoku performance. A numerically oriented task was selected to prevent participants from engaging with/rehearsing experimental materials.

Final Assessment Phase

The procedure was the same as in the Generation Phase. The target picture (without label) was presented for up to 1500 ms or until a naming response was registered. A tone sounded and a "too slow" message appeared for 200 ms if the time limit was exceeded. Another trial began 1000 ms after the previous one. Following the completion of this phase, participants were thanked and received an educational debriefing.

Results

All data were coded for errors offline by trained research assistants using the recorded audio from the experimental session. All trials with a response time of less than 250 ms and trials in which an environmental sound triggered the voice key were considered erroneous and dropped from all analyses. All trials in which a participant did not fluently respond within the response window were coded as omission errors, and errors in which a wrong picture name was used were coded as commission errors. These salient naming errors were those used in the analysis of errors.

All analyses were conducted in R version 4.3 using the *afex* package (Singmann & Kellen, 2019). A mixed model approach with Satterthwaite approximations was used for each analysis.

Generation Phase

Latency Analysis

Descriptively, naming times increased across Ordinal Positions (see Figure 8), though unexpectedly not in the second position. A linear mixed model analysis was conducted with Ordinal Position as the fixed factor and random intercepts specified for both participants and items. As predicted, there was a significant main effect of Ordinal Position (F (3,1276)=13.17, $p < .01$), indicating the robust presence of cumulative interference.

Error Analysis

The error rate was quite low (8.5%). Of all errors, 77% were salient naming errors. Of the 105 salient errors, 59 were omission errors and 46 were commission errors. Descriptively, errors were consistent across Ordinal Positions, (N_{Q1}=21, N_{Q2}=29, N_{Q3}=31, N_{Q4}=24). A logistic mixed model analysis was conducted with Ordinal Position as the fixed factor and a random intercept

for items. There was no significant effect of Ordinal Position (χ^2=1.35, p > .05) indicating that error likelihood did not differ across Ordinal Positions.

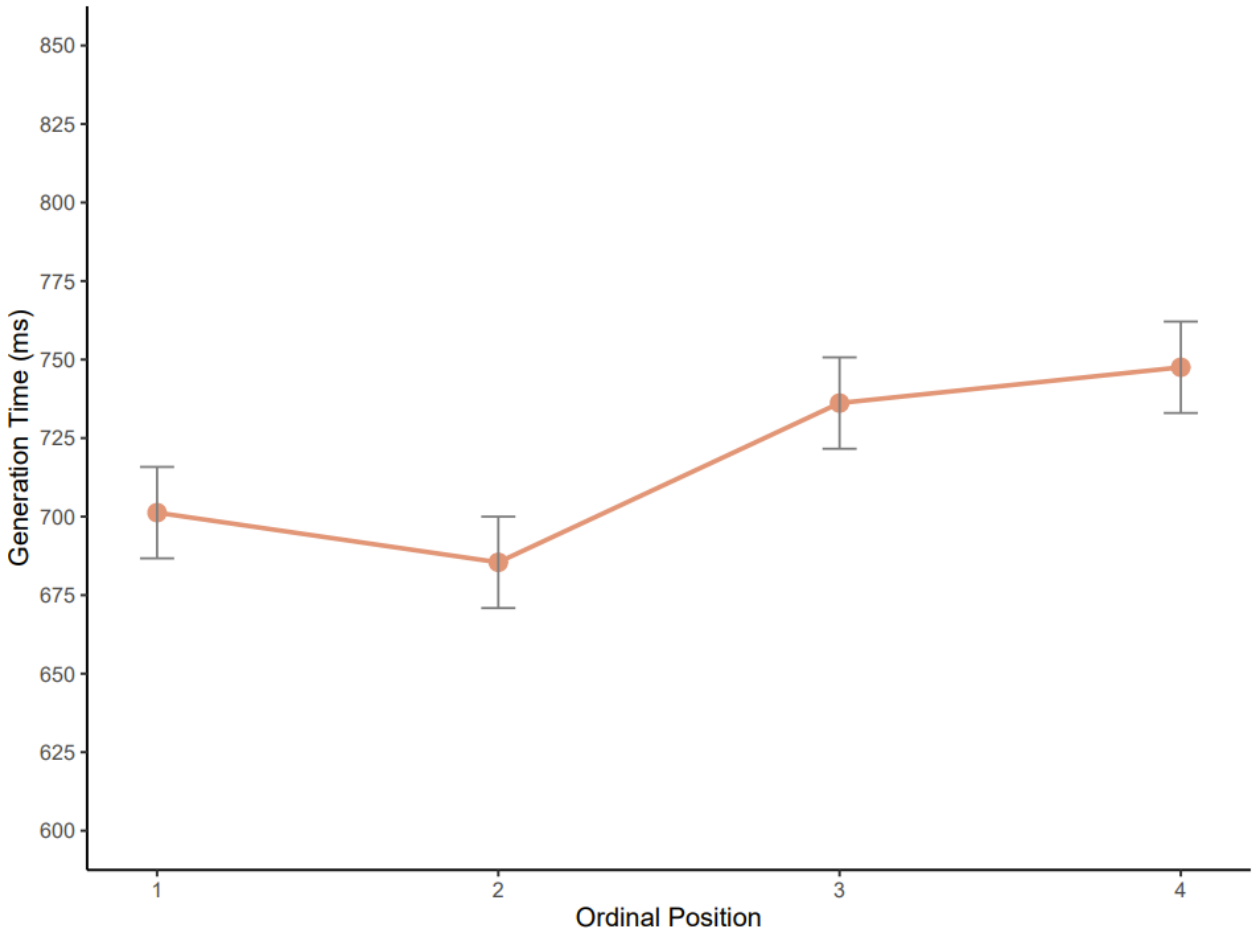

Figure 8. Experiment 3A: Cumulative interference as a function of Generation Time and Ordinal Position in the Generation Phase.

Final Assessment Phase

Latency Analysis

Descriptively, naming times increased across Ordinal Positions (see Figure 9). Unexpectedly, there was no meaningful difference in naming time between Activated (M=783, SE=14) and Control (M=782, SE=14) conditions.

A linear mixed model analysis was conducted with Memory Type, Ordinal Position, and their interaction as the fixed factors and random intercepts specified for both participants and items. There was a robust main effect of Ordinal Position ($F(3,2606)=53.0$, $p<.001$), indicating the presence of cumulative interference in both conditions. There was no main effect of Memory Type ($F(1,2608)<1$), and no interaction with Ordinal Position, $F(3,2606)<1$. That is, there was no observed RIF effect in this experiment. Given the significant RIF effects observed in prior experiments in this dissertation, this finding is quite surprising, but may underscore the utility of prior design choices. I will return to this issue in the Discussion.

Error Analysis

Overall, the error rate of 10% was again quite low. 90% of the errors were salient naming errors. Of these 308 salient errors, 175 were omission errors, and 136 were commission errors. Error rates were similar across Memory Conditions, with only slightly more errors observed for Activated items (N=182) relative to Control, N=162. Error rates were similar across Ordinal Positions, $N_{Q1}=71$, $N_{Q2}=84$, $N_{Q3}=76$, $N_{Q4}=85$). A logistic mixed model analysis was conducted with Memory Type, Ordinal Position, and their interaction as the fixed factors and with a random intercept specified for items. There was no effect of Memory Type ($\chi^2=0.88$, $p> .05$) or Ordinal Position($\chi^2=2.39$, $p> .05$), and the interaction was also not significant, $\chi^2=3.05$, $p> .05$. Thus a RIF effect was not observed in errors.

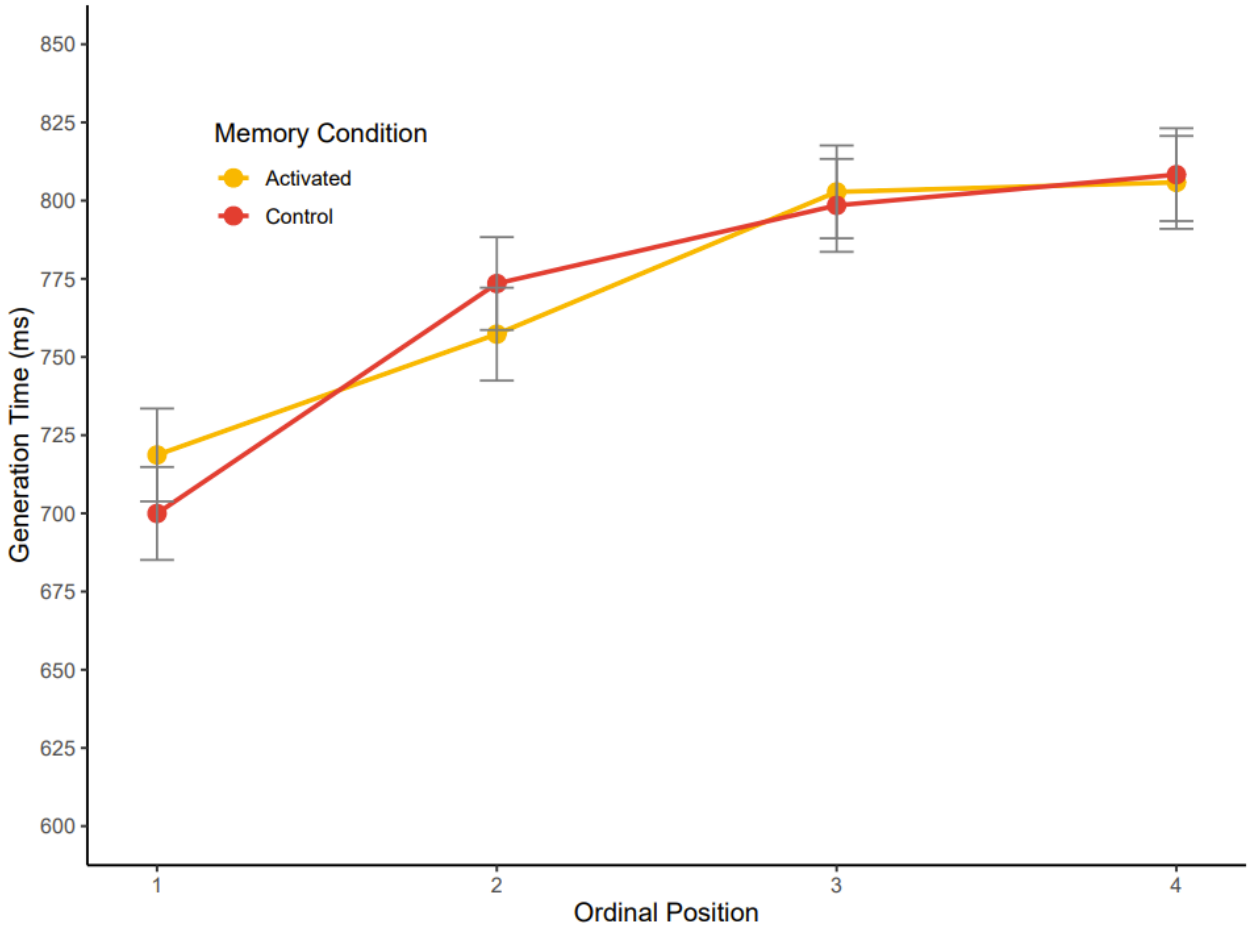

Figure 9. Experiment 3A: Generation Time as a function of Ordinal Position and Memory Condition in the Final Assessment Phase

Experiment 3B: Picture Naming to Picture Naming with Overnight Retention Interval

This iteration of the experiment was designed to assess the role of sleep-based memory consolidation processes in preserving adaptive changes to conceptual-lexical access. Thus the design was the exact same as the previous Picture Naming + Picture Naming experiment, with the exception that the Final Assessment Phase took place the following day after a period of nocturnal sleep.

In line with the temporal insensitivity claims of Oppenheim et al. (2010) and Norman et al. (2007), I retained the predictions from Experiment 3A. Specifically, I predicted interference

for the Activated Condition relative to control, despite the fact this difference was not statistically significant in Experiment 3A.

Method

Participants and Power Considerations

80 participants were again recruited from Lehigh University in return for class credit in an introductory psychology course. Due to recording equipment malfunction, four participants were dropped from the Generation Phase analysis. Given that their Final Assessment Phase data were still valid, they were retained in the final analyses. In the Final Assessment Phase, 2 participants were dropped due to equipment malfunction and 11 participants were lost to attrition, resulting in a final N=67.

Materials and Apparatus

The materials and equipment were the same as those used in the previous experiment.

Design

The design was the same as the previous experiment with the exception that there was no filler task and instead the experiment was split up into two sessions. During the initial sign-up procedure, participants were asked to sign up for a second timeslot the day after the initial session. To increase participation rates, participants could schedule the second timeslot to occur at any time on the following day. The average number of hours between sessions was 21.7 hr (SD=2.5), with the maximum lag being 29 hours and 17 hours the minimum. In the first session, participants underwent the Familiarization sequence and the Generation Phase. In the second, they only completed the Final Assessment Phase.

Procedure

The experiment comprised the same by-Phase procedures as Experiment 3C except that there was no Filler activity. In the first session of the experiment, participants were first asked to generate a unique identification code that would be used to anonymously link their data across the two experimental sessions. They then completed the Familiarization sequence and Generation Phase. Following completion of the Generation phase, participants were instructed to return to the lab the following day and to refrain from discussing the experiment with their classmates. At the beginning of the second session they were asked to provide their unique participation code before completing the Final Assessment Phase. Participants only received credit if they completed both parts of the experiment.

Results

Data were coded for errors offline by trained research assistants using the recorded audio from the experimental session in the same way as for Experiment 3C. The analytic approach was also the same.

Generation Phase

Latency Analysis

As in the previous experiments, generation time increased across Ordinal Positions (see Figure 10). A linear mixed modelling approach was used, with the final model including a fixed effect of Ordinal Position and random intercepts for both participants and items. The effect of Ordinal Position was significant (F (3,1150)=7.77, $p < .001$), reflecting the presence of cumulative interference.

Error Analysis

The overall error rate in this phase was 11%. Of these errors, 89% were salient naming errors. Of the salient naming errors, 85 were omission errors and 64 were commission errors. Errors were similar across Ordinal Positions, (N_{Q1}=40, N_{Q2}=30, N_{Q3}=46, N_{Q4}=43). A logistic mixed model analysis was conducted with a fixed effect of Ordinal Position and random intercepts for participants and items. The effect of Ordinal Position was not significant (χ^2=3.49, p >0.5), indicating that error likelihood did not differ across the position of related items in the sequence.

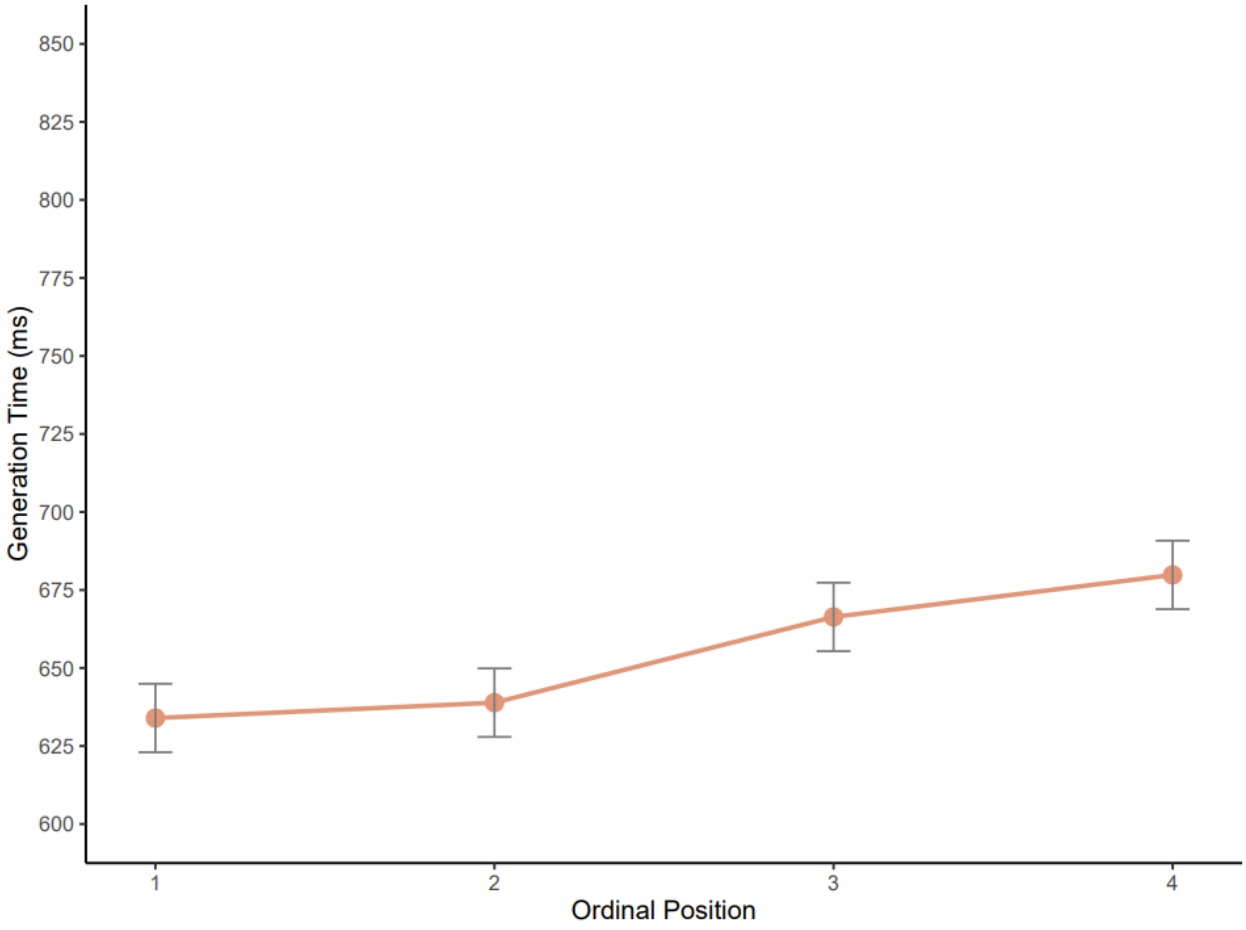

Figure 10. Experiment 3B: Generation Time as a function of Ordinal Position in the Generation Phase.

Final Assessment Phase

Latency Analysis

Descriptively, naming times increased across Ordinal Positions (see Figure 11) and the average naming time for the Activated condition (M=736, SE=17) was slightly longer than in the Control condition, M=728, SE=17. A linear mixed model specified Ordinal Position, Memory Condition, and their interaction as fixed factors and random intercepts for both participants and items. There was again a main effect of Ordinal Position ($F(3,2100)=29.56$, $p<.001$, reflecting robust cumulative interference. However, the effect of Memory Condition was not statistically significant ($F(1,2100)=1.36$, $p>.05$. That is, pictures semantically related to pictures named the previous day did not exhibit heightened interference compared to Controls. The interaction between Ordinal Position and Memory Condition was also not significant, $F(3,2098)<1$.

Error Analysis

The overall error rate in this phase was 13%. Of these errors, 85% were meaningful naming errors. Of naming errors, were 162 omission errors and 143 were commission errors. Descriptively, error proclivity was greater in the Activated condition (N=169) compared to Control (N=136) and did not significantly differ across positions ($N_{Q1}=70$, $N_{Q2}=82$, $N_{Q3}=77$, $N_{Q4}=76$). Due to data sparsity, the logistic mixed model analysis was conducted with Memory Condition included as the fixed factor and a random intercept specified for participants. There was a significant main effect of Memory condition ($\chi^2=4.35$, $p= .037$), indicating that the greater errors in the Activated condition relative to the Control condition is meaningful. Thus, although the slight cost in latencies (Fig 11) was not significant, naming was more erroneous in the Activated condition where related name generation took place the previous day, providing some tentative evidence for overnight retrieval-induced semantic interference.

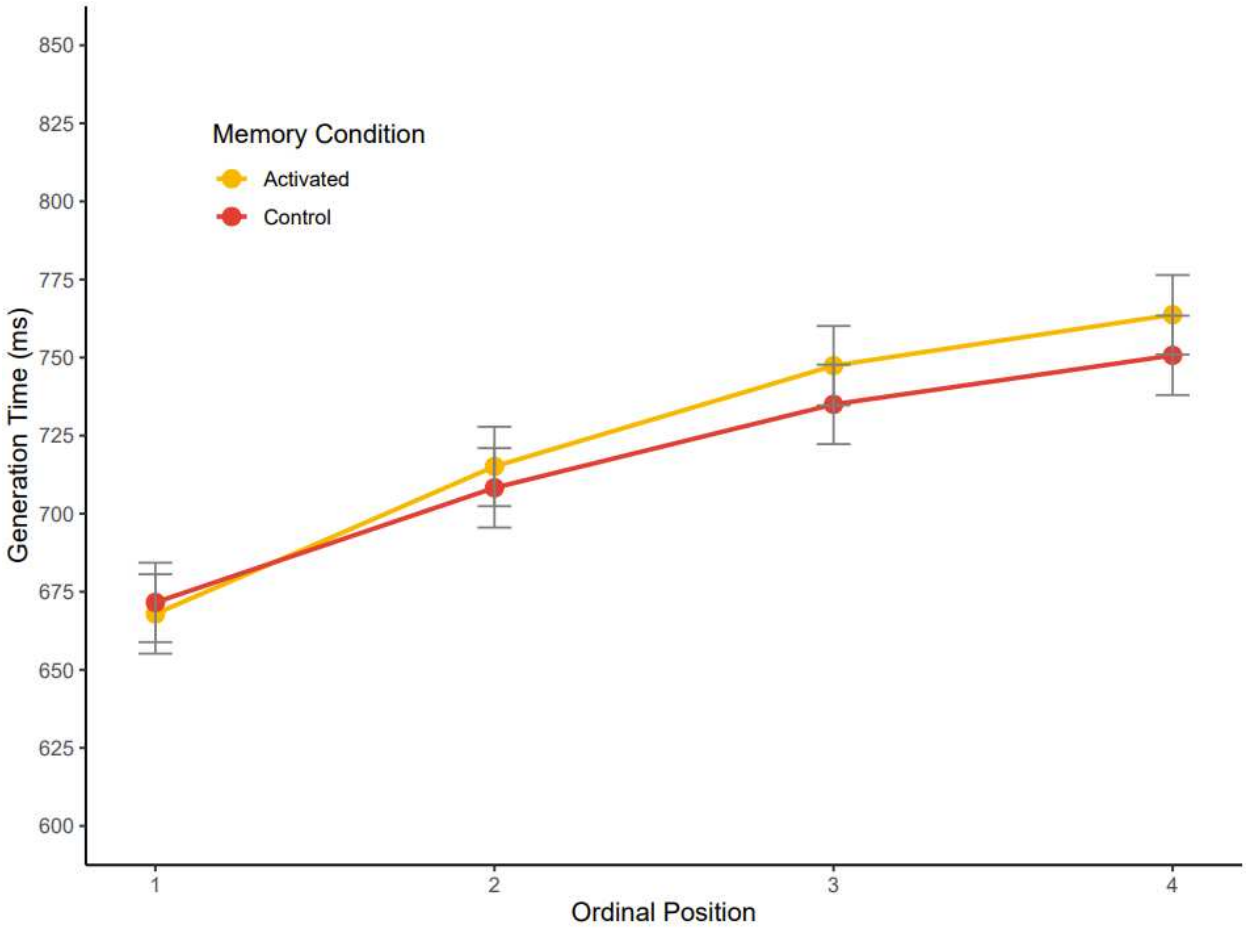

Figure 11. Experiment 3B: Generation Time as a function of Ordinal Position and Memory Condition in the Final Assessment Phase.

Experiment 3C: Picture Matching to Picture Naming – 15 Minute Retention Interval

This experiment sought to investigate whether strengthened conceptual coactivation hinders subsequent generation of related picture names. The present design was the same as the previous, with the exception that the Generation Phase was replaced with a Learning Phase that involved a picture-matching task. Picture matching is thought to only require conceptual processing. This phase was followed by the same 15-minute retention interval and picture naming Final Assessment Phase as in Experiment 3A. In the Pilot Experiment, I found cumulative facilitation across related matching positions. This may seem counterintuitive to a

prediction of interference in the Activated condition in the Final Naming Assessment Phase. As discussed previously (see *Interim Discussion),* I posit that the facilitation across ordinal positions reflects strengthened connections between shared features and related lexical concepts (Belke, 2013). I note that this supposition is consistent with past work on long-term conceptual priming (e.g., Becker et al., 1997; Joordens and Becker, 1997; Was et al., 2019; Tse & Neely, 2007; Hughes & Whittlesea, 2003). The vast majority of work on conceptual facilitation involves non-generative categorization tasks, but they do not assess the long-term consequences of the increased accessibility of related items. I suggest that if the facilitation observed for dispersed relations in the matching task is due to long-term strengthening processes (e.g., Belke, 2013; Was et al., 2019), these categorically related items would be especially coactive when a related item is encountered in the following assessment. This heightened categorical coactivation would induce interference for related items when the retrieval and selection of a single representation (name) is required. I thus sought to assess if cumulative facilitation promotes heightened interference for related items (Activated condition) in a subsequent generative context. Given that I did not observe a significant RIF effect in the previous picture naming experiments, it would be especially notable if the present design, which explicitly employs pre-lexical, conceptually based processing, elicited interference in the Activated condition.

Method

Participants and Power Considerations

As in the previous experiment, 80 participants were recruited from Lehigh University in return for class credit in an introductory psychology course. Due to either excessive error rate or equipment malfunction, 8 participants were dropped from the analyses, resulting in a final N=72.

Materials and Apparatus

The materials were the same as those used in the previous experiments. The matching task materials were drawn from the Pilot Experiment and the picture naming materials were the same as in Experiments 3A and 3B.

Design

The experiment comprised four sub procedures, including an initial familiarization procedure, a Picture Matching Learning Phase, a filler task, and a final Picture Naming Assessment Phase. As in the previous experiments, the two critical phases comprised two distinct but linked designs (see below). Assignment of categories to the Matching Phase and to the Activated and Control conditions was balanced as in previous experiments. Only half of the items in the Control condition were presented to equate the number of items across conditions, and the half presented was counterbalanced across experimental versions.

Matching Phase

The procedure was the same as the Pilot Experiment.

Final Naming Assessment Phase

This phase was identical to that of the previous two experiments.

Procedure

The experiment comprised four separate procedures.

Familiarization

The procedure was the same as in the previous experiment, with the exception that participants were also familiarized with the central picture cues in addition to future targets.

Learning Phase

The procedure was the same as in the Pilot Experiment.

Filler Task

Participants worked on a printed medium difficulty level sudoku puzzle for 15 minutes as in other experiments.

Final Assessment Phase

The procedure was the same as the final Naming Phase in the previous experiments.

Results

Naming data were coded for errors offline by trained research assistants, as in the previous experiment. Matching performance was automatically scored, and incorrect trials were dropped from latency analyses.

Learning Phase

Latency Analysis

Descriptively, matching times decreased over the first three Ordinal Positions (see Figure 12). A linear mixed model analysis was conducted with Ordinal Position as the fixed factor and random intercepts specified for participants and items. The main effect of Ordinal Position was significant, $F(3,1174)=11.36$, $p < .001$. In line with the Pilot Experiment and opposite to the previously reported picture naming data, latencies significantly *decreased* over Ordinal Positions.

Error Analysis

Matching error rate was 11%. Descriptively, errors were roughly equivalent across Ordinal Positions, $N_{Q1}=40$, $N_{Q2}=37$, $N_{Q3}=37$, $N_{Q4}=38$. A logistic linear mixed model analysis was conducted with Ordinal Position as the fixed factor and a random intercept for items. There was no main effect of Ordinal Position ($\chi^2=0.22$, $p> .05$). Error likelihood did not differ across position in the matching sequence.

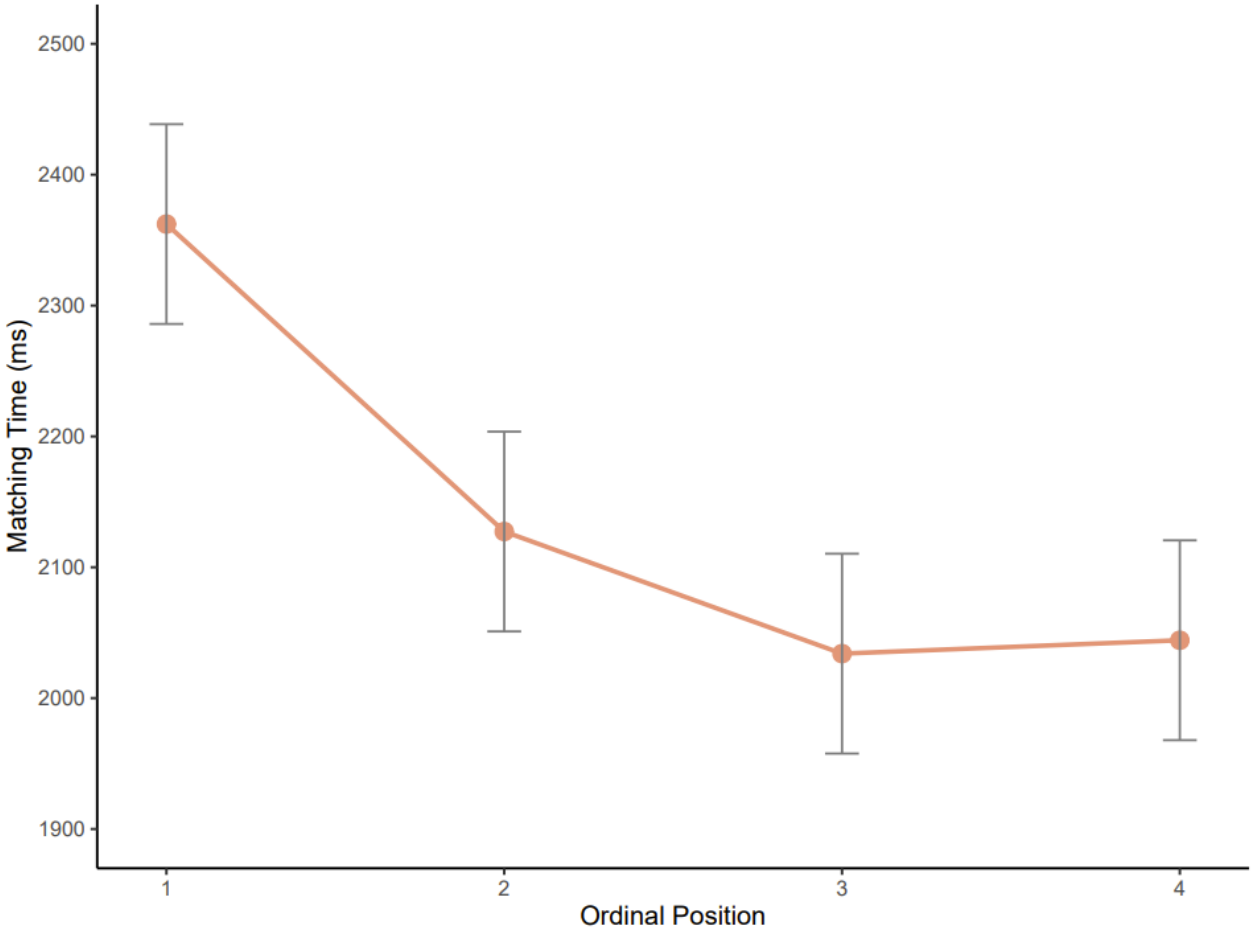

Figure 12. Experiment 3C: Matching Time as a function of Ordinal Position showing cumulative facilitation in the Learning phase.

Final Assessment Phase

Latency Analysis

Descriptively, naming times increased over Ordinal Positions in both conditions (see Figure 13), and Activated (M=770, SE=17) and Control (M=765, SE=17) conditions did not meaningfully differ. A linear mixed model analysis was conducted with Memory Condition, Ordinal Position, and their interaction included as fixed factors and random intercepts for both participants and items. The main effect of Ordinal Position was significant ($F(3,2206)=9.55$, $p < .001$), reflecting the presence of cumulative interference for both conditions. As in the previous

experiment, the effect of Memory Condition was not significant ($F(1,2213)<1$) Nor was the interaction with Ordinal Position significant, $F(3,2206)<1$. That is, there was again no significant RIF effect. It is notable that the results of the present Final Assessment Phase are roughly equivalent with the previous experiments', even though the present experiment implemented non-generative picture matching during the Learning Phase and observed cumulative facilitation.

Error Analysis

Error proclivity (18%) was somewhat higher than in previous experiments. Of the total errors, 89% were salient naming errors. The salient error rate was slightly higher in the Activated condition (N=251) compared to Control (N=233). Of all salient errors, 271 were omissions and 213 were commission errors. Errors were relatively stable across positions, $N_{Q1}=136$, $N_{Q2}=99$, $N_{Q3}=126$, $N_{Q4}=123$. A logistic mixed model analysis was conducted with Memory Type, Ordinal Position, and their interaction as the fixed factors with a random intercept specified for items. There was no effect of Memory Type ($\chi^2=0.14$, $p> .05$). However, there was a main effect of Ordinal Position ($\chi^2=9.44$, $p= .024$), which was further qualified by a marginally significant interaction with Memory Condition, $\chi^2=6.89$, $p= .076$. Subsequent follow up tests with Tukey corrections indicated that in the first Ordinal Position, there were significantly more errors in the Activated condition compared to the Control condition, $z= 2.13$, $p = .03$. No other contrasts were significant. Thus, whereas there was not a RIF effect in latencies, there is some (albeit limited) evidence that naming pictures related to previously matched pictures was more difficult in the initial Ordinal Position.

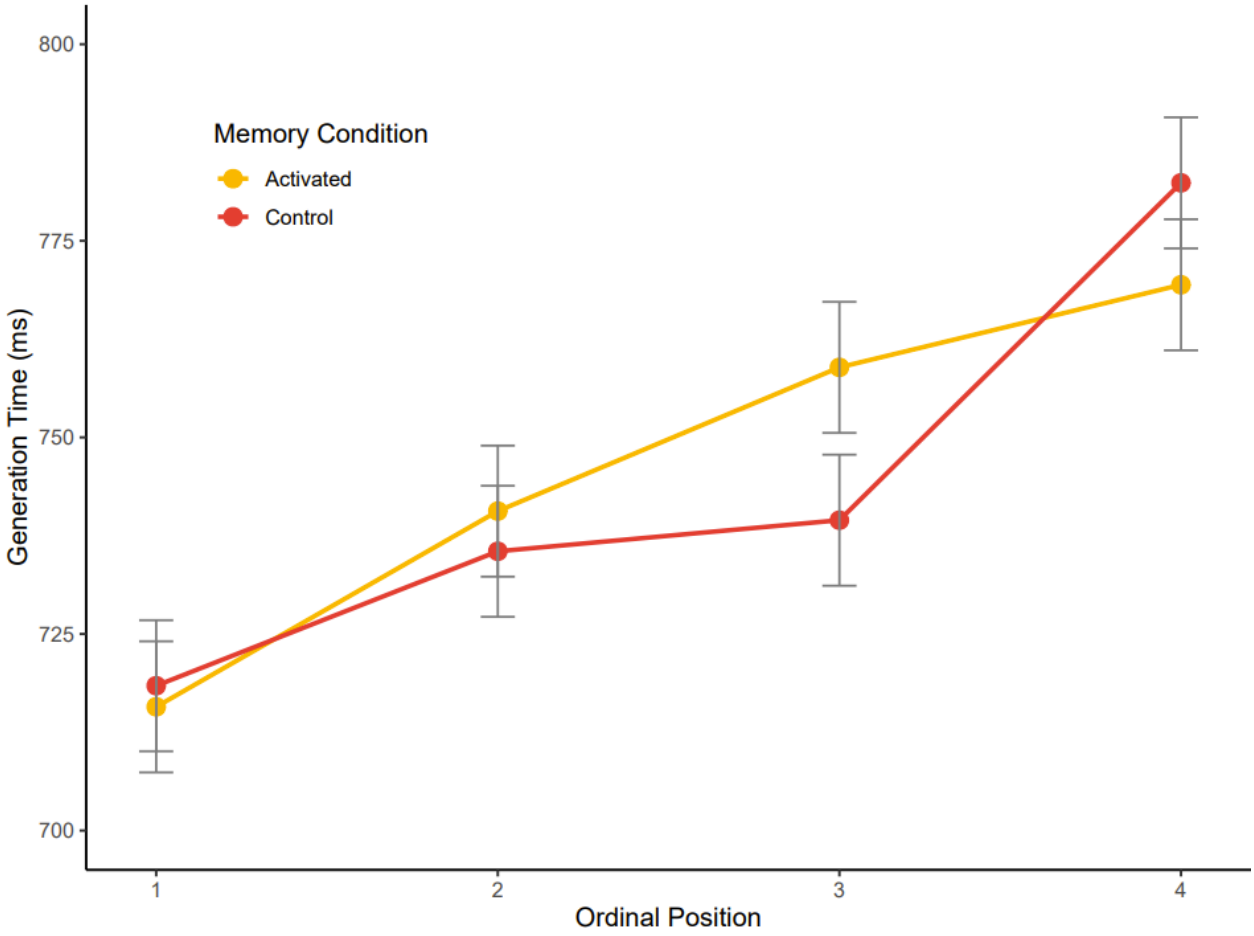

Figure 13. Experiment 3C: Generation Time as a function of Ordinal Position and Memory Condition in the Final Assessment Phase.

Experiment 3D: Picture Matching to Picture Matching – 15 Minute Retention Interval

The results of the previous experiment indicate that when lexical processing is not necessitated during semantic retrieval, cumulative semantic facilitation was observed across related items. However, there was some evidence in the Final Assessment Phase that not only does subsequent generative naming elicit typical cumulative interference, but the facilitation from the previous phase translated to slightly increased naming errors in early Ordinal Positions.

Thus these results provide some preliminary evidence that interference is primarily observed in paradigms requiring verbal retrieval. If true, this is consistent with the claim that conceptual level priming is the origin of semantic interference. However, Belke (2013) suggests that although conceptual adaptation may be the originating cause, interference is only expressed when lexical retrieval and selection are engaged. The present experiment was designed to investigate what happens when lexical generation is not engaged during the Final Assessment Phase. Recall that past work (e.g., Was et al. 2019) found that semantic retrieval (without generation) facilitated later judgements of new related category members. It follows then that, if picture matching elicits long-term conceptual strengthening, matching of new category members should be facilitated in comparison to unrelated controls. In the previous experiment, I predicted that the long-term priming that occurred in the Matching Phase would result in heightened coactivation of semantic competitors during the Final Naming Assessment Phase and make production, which entails the retrieval and selection of a single lemma, more difficult. In contrast, for picture matching in the Final Assessment Phase, there is no discriminatory retrieval and selection of a single lemma, and so the strengthened coactivation of related concepts may facilitate processing rather than hinder it (Becker et al., 1997; Belke, 2013). It remains possible that some degree of downregulation is also involved (e.g., Belke, 2013; Norman et al., 2007), but it may be outweighed by conceptual-level facilitation. The final experiment in this component thus employed a second phase of Picture Matching during the Final Assessment phase in place of generative Picture Naming. In line with the previous results, I again predicted cumulative facilitation in the first Matching Phase. For the Final Assessment Phase, I predicted cumulative facilitation across related matching positions, and that matching pictures related to previously matched pictures would be facilitated compared to Controls.

Method

Participants and Power Considerations

80 participants were recruited from Lehigh University in return for class credit in an introductory psychology course. Due to equipment malfunction, 6 participants were dropped from the analyses, resulting in a final N=74.

Materials and Apparatus

The materials and apparatus were the same as those used in the previous experiment but matching materials were presented in both phases.

Design

The design mirrored that of the previous experiment with the exception that the final phase comprised another sequence of picture matching instead of picture naming. The two critical phases comprised two distinct but linked designs (see below). Counterbalancing procedures were the same as in the previous experiments.

Learning Phase

The design was the same as the Pilot and previous experiment (3C).

Final Assessment Phase

This phase mirrored that of the Learning Phase, with the exception that pictures were either related (Activated condition) or unrelated (Control condition) to previously matched pictures. One item from each Activated and Control category was randomly assigned to each quartile. Thus, there were two within-subject factors: Memory Condition (Activated versus Control) and Ordinal Position (1-4).

Procedure

The experiment comprised four separate procedures.

Familiarization

The procedure was the same as the previous experiment.

Learning Phase

The procedure was the same as in the prior experiment.

Filler Task

Participants worked on a printed medium difficulty level sudoku puzzle for 15 minutes.

Final Assessment Phase

The procedure was the same as the previous Matching Phase. Following the completion of this phase, participants were thanked and received an educational debriefing.

Results

All trials with a response time of less than 250 ms were considered erroneous and dropped from all analyses. Matching performance was automatically scored, and incorrect selections were dropped from the primary analyses.

Matching Phase

Latency Analysis

Descriptively, matching times decreased across the first three positions in the sequence, see Figure 14. A linear mixed model analysis was conducted with Ordinal Position as the fixed factor and random intercepts for participants and items. There was a main effect of Ordinal Position ($F(3,1178)=3.04$, $p = .028$), such that matching times were significantly facilitated across the sequence (although there was some fluctuation in the final position). Thus as in the previous experiment and initial pilot experiment, nongenerative picture matching elicited cumulative facilitation rather than interference.

Error Analysis

The error rate was 10%. Descriptively, errors tended to decrease across Ordinal Positions, N_{Q1}=43, N_{Q2}=40, N_{Q3}=35, N_{Q4}=24. To formally assess how error rate changed across Ordinal Positions, a logistic mixed model analysis was conducted with Ordinal Position as the fixed factor and a random intercept for items. There was a main effect of Ordinal Position (χ^2=8.49, p= .037), such that error likelihood decreased across Ordinal Positions.

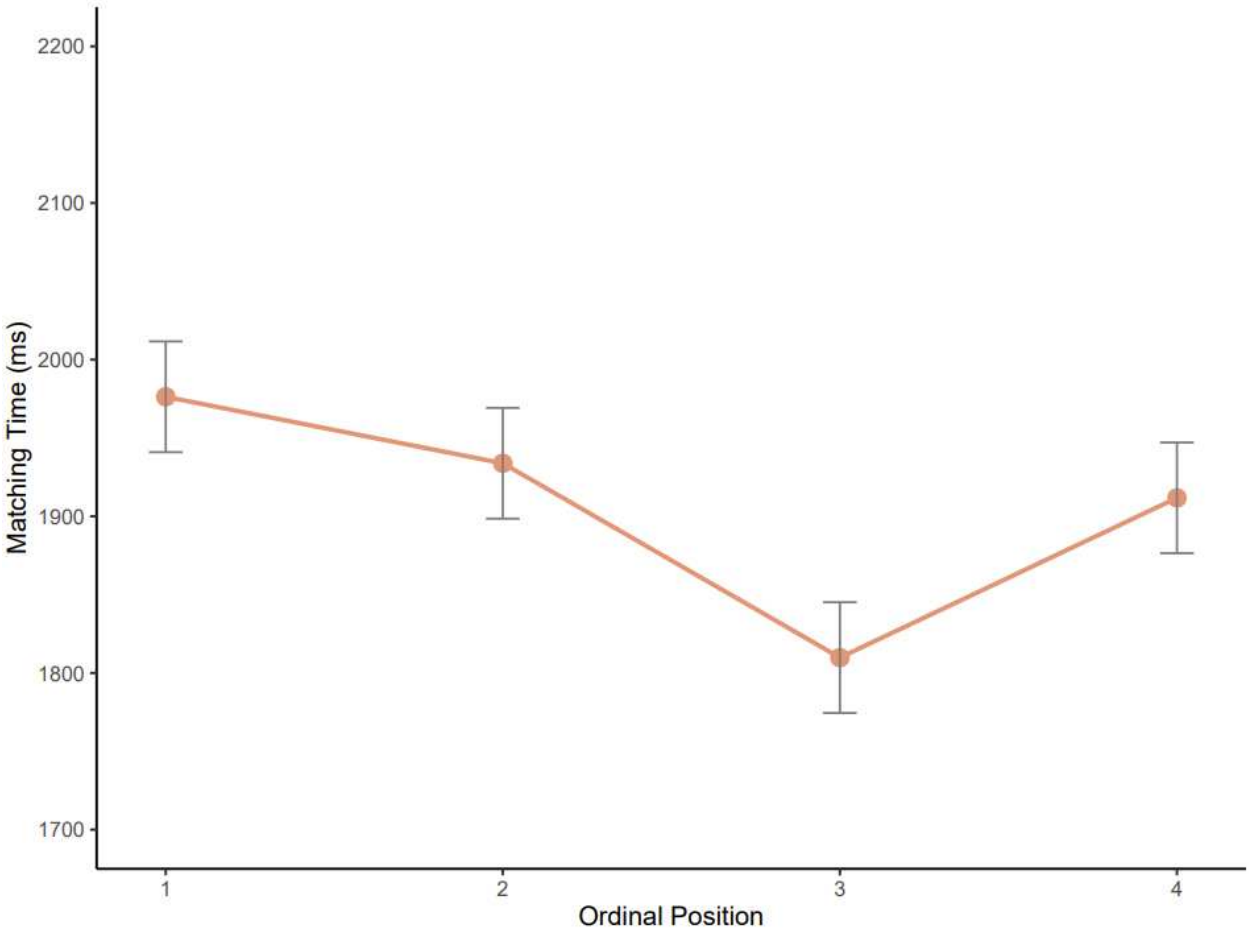

Figure 14. Experiment 3D: Matching Time as a function of Ordinal Position showing cumulative facilitation in the Learning phase.

Final Matching Assessment Phase

Latency Analysis

Descriptively, matching times tended to decrease across most Ordinal Positions, although this pattern was nonlinear and unstable (see Figure 15). Contrary to the predictions, Matching times were equivalent in the Activated (M=1990, SE=75) and Control (M=1989, SE=75) conditions. A linear mixed model analysis was conducted with Ordinal Position, Memory Condition, and their interaction specified as fixed factors and random intercepts for both participants and items. The analysis confirmed that the main effect of Memory Condition was not significant ($F(1,2371)<1$), reflecting that, contrary to prediction, Activated matching was not facilitated compared to Control. Contrary to the previous phase, the main effect of Ordinal Position was also not significant ($F(3,2373)=1.56$, $p>.05$). Lastly, the interaction between Memory Condition and Ordinal Position was marginally significant, $F(3,2372)=2.40$, $p=.07$. Subsequent pairwise comparisons with Tukey corrections indicated that the Activated condition was matched more quickly than controls, but only in the second Ordinal Position. Given the marked instability across positions, this is interpreted with caution.

Error Analysis

The overall matching error rate was 12% and there were slightly more errors in the Activated (N=183) condition compared to the Control (N=164) condition. Errors somewhat decreased across Ordinal Positions, $N_{Q1}=103$, $N_{Q2}=96$, $N_{Q3}=79$, $N_{Q4}=69$. A logistic mixed model analysis was conducted with Memory Condition, Ordinal Position, and their interaction as fixed factors and a random intercept for items. There was no main effect of Memory Condition ($\chi^2=1.28$, $p>.05$), indicating that error proclivity did not differ based on prior related picture matching. Consistent with the previous phase, there was a marginal effect of Ordinal Position

(χ^2=7.26, p= .06), in which error rate decreased across ordinal positions. The interaction between Memory Condition and Ordinal Position was not significant, χ^2=4.99, p>.05. Thus, although there was no overall cumulative facilitation in latencies, there was some marginal evidence of cumulative facilitation as indexed by a pattern of decreased errors over Ordinal Positions.

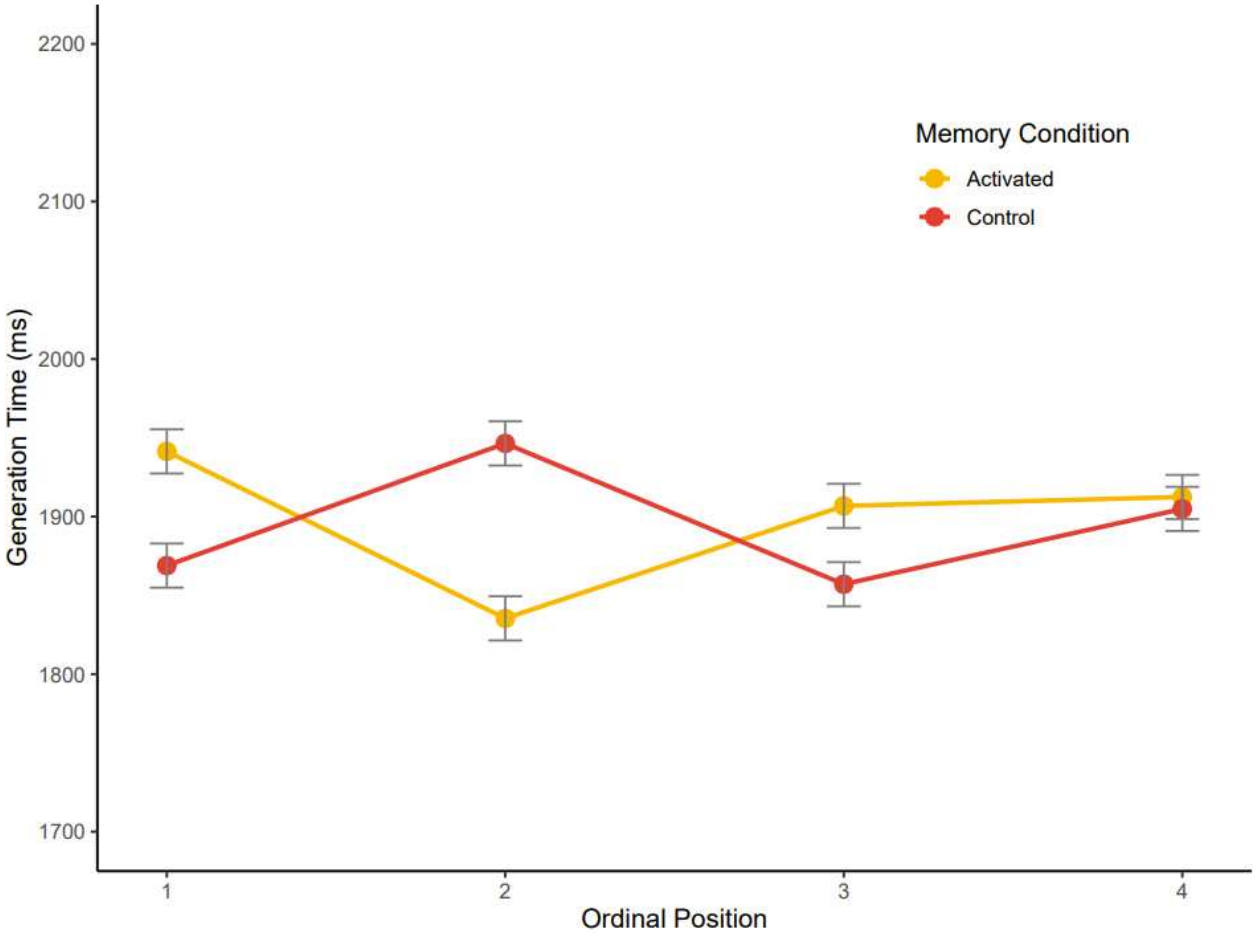

Figure 15. Experiment 3D: Matching Time as a function of Ordinal Position and Memory Condition in the Final Assessment Phase.

Discussion

The third component of the dissertation sought to clarify the origin of semantic interference and its durability. Experiments 3A and 3B implemented a multiphase continuous naming design inspired by the integrated retrieval practice paradigm developed in the prior two components of the dissertation. After being familiarized with all pictures, participants completed a generative picture naming phase containing a subset of items, a retention interval, and then a final naming phase. The final phase compared naming performance for pictures related to previously named items and unrelated controls, which is essential to provide a valid test of durability. The designs were the same in Experiments 3A and 3B, with the exception that the retention interval was 15-minutes in Experiment 3A and overnight in Experiment 3B. In the first two components of the dissertation, I observed a retrieval-induced semantic interference effect in picture naming latencies following category-stem cued generation in the Generation Phase. I concluded that category-stem cueing and picture name generation involve similar processes of semantic activation and interference. Therefore, I expected to observe the same retrieval-induced interference for related Activated pictures compared to unrelated controls. Experiment 3A, which utilized the 15-minute Retention Interval used in the first dissertation component, produced unexpected results. In both the Generation and Final Assessment Phases, I observed the expected cumulative interference. However, there was not a significant cost to the Activated condition relative to Controls, indicating that prior related picture name generation did not significantly affect conceptual-lexical access in the final phase. The Overnight Retention Interval (Experiment B) produced a similar pattern in latencies in both phases, but again did not show a significant cost to the Activated condition. However, the latencies were in the predicted direction, and in this experiment, there were significantly more errors in the Activated condition compared to

Control. This provides some tentative evidence that sleep-based consolidation processes supported long-term adaptations to conceptual-lexical access. However, given that the effect was only observed in errors and not latencies, more work is needed to substantiate this claim. This tentative finding is in line with past work, such as the finding that sleep can bias semantic processing in favor of subordinate homophone meanings (e.g., Gaskell et al., 2019), but the role of consolidation in conceptual-lexical access remains understudied.

Experiments 3C and 3D examined semantic interference arising from conceptual-level processing. Rather than generative picture naming, a pre-lexical picture-matching task was implemented in the initial Learning Phase. This task was a novel variation of the matching paradigm initially developed by Campanella and Shallice (2011) and adapted by Wei & Schnur (2016). In Experiment 3C, I sought to assess how the cumulative facilitation observed in this task would translate to a subsequent phase of generative picture naming. Experiment 3D used the same matching task in the Learning Phase, but instead sought to assess if cumulative facilitation would further enhance picture matching performance for semantically related items relative to controls. In both experiments, I observed the same cumulative facilitation effect in the Learning Phase that was found in the initial pilot study. That is, matching time decreased across Ordinal Positions. In Experiment 3C, I observed overall cumulative *interference in* the following Final Naming Assessment phase, as is typically observed in continuous picture naming. However, there was no significant cost of prior related matching on naming latencies, and only a hint of such costs in errors. In Experiment 3D, the Final Matching Assessment Phase did not show significant cumulative facilitation (although errors decreased across the sequence) and there was no difference between Activated and Control conditions in either latencies or errors.

Several questions emerge from this complex pattern of results. First, why was there so little retrieval-induced cost in latencies following picture naming in the Generation Phase? I suggest two possible interpretations. In addition to the switch to picture naming, the methodology of the Generation Phase and later Assessment Phase was purposefully simplified to emulate the typical continuous naming task. In the Generation Phase, I implemented a single pass through the materials rather than the three repetitions used in the prior components. Although the results of Components 1 and 2 suggest that adaptive learning drops off significantly after the first repetition, it is possible that additional exposure nevertheless supports conceptual-lexical adaptation by reinforcing the categorical relatedness of items with a shared category label. In the Final Assessment Phase, participants again completed the same form of picture naming, but this time the "flash" of the upcoming category used in the prior two components was omitted. It is possible that the multiple repetitions in the Generation Phase and the overt presentation of category labels in either phase promoted the coactivation and subsequent downregulation of words linked to the same category label. I note that this supposition is contradictory to the assumption of cue independence shared by both literatures. For example, cumulative interference is readily observed in all of the continuous picture naming phases of the present set of experiments (and in past literature) even though a shared category label was never presented, suggesting that an overtly comprehended category cue is not necessary to observe interference. However, it is possible that shared category cues may serve a more significant role in multiphase paradigms with extensive retention intervals. Alternatively, it is possible that the present lack of cross-phase effects is due to attenuated learning in the Generation Phase. That is, it is possible that learning in the Generation Phase must be robust to transfer to a later phase.

Given that the current iteration of the Generation Phase only entailed 20 items, this may have been too brief to establish the necessary long term downregulation.

I also found that there were significantly more errors in the Activated condition compared to Control, but only when the Final Assessment Phase took place after nocturnal sleep. Given that there was no effect on the error rate when there was only a 15-minute Retention Interval (Experiment 3A), this finding is somewhat surprising. It appears that sleep does not simply strengthen interference that is already visible in the short term but can heighten the net outcome of downregulatory adaptive learning. The present results thus point to a possible role of sleep-based consolidation in maintaining recently acquired modulations to conceptual-lexical access, but given the lack of effect in latencies, more work is needed to substantiate this claim.

Why was the cumulative facilitation elicited by picture matching not long lasting? Following the unpredicted cumulative facilitation observed in the Pilot Experiment, I concluded that nongenerative picture matching elicited long-term conceptual strengthening rather than interference. I hypothesized that this increased coactivation would translate to interference for related Activated pictures when single words must be generated in the Final Assessment Phase. In contrast, I predicted that when generative processes were not engaged at final test, this heightened coactivation would result in relative *facilitation* when matching related pictures compared to unrelated controls. While I found overall cumulative interference in the Picture Naming assessment of Experiment 3C, there was no interference resulting from the prior related matching (although there were marginally more errors). In addition, there was no clear overall pattern of cumulative facilitation in the picture-matching assessment phase of Experiment 3D, and Activated pictures were not matched more quickly or accurately than Controls. If the incurred facilitation was long-lasting enough to survive a significant lag of unrelated trials, why

did it not continue into the Final Assessment Phase? A significant factor could be that the majority of past work examining long-term conceptual priming views 'longevity' in much the same way as the language production literature. For example, the long-term conceptual priming in Woltz et al. (2010) and Was et al. (2019) was found after a lag of 10 unrelated trials and after 5 seconds, respectively. It has long been assumed that if a priming effect can be observed after a handful of unrelated items or a few seconds, it cannot be explained by momentary coactivation processes, and should therefore hold across much longer temporal lags. The present results show that this may not necessarily be the case. Much more data is needed to establish whether adaptive learning (regardless of direction) persists across extensive temporal lags. Alternatively, regarding the lack of relative facilitation for the Activated condition in Experiment 3D, it is possible that since picture matching entails conscious evaluation of relatedness rather than relying on rapid, reflexive picture name generation, it may simply not be sensitive enough to detect the relative facilitation of Activated condition items. Given the novelty of the picture matching task used in the present studies, additional work is needed to clarify if these null findings reflect methodological limitations or the nature of long term conceptual priming.

In sum, it is difficult to draw clear conclusions about the origin and locus of retrieval-driven semantic interference from these studies. I suggest that the present findings generally support the proposal by Belke (2013), in which conceptual level adaptation is the origin of semantic interference, while the interference itself is only expressed through lexical retrieval and selection. If the results of the picture matching task reflect true long term conceptual strengthening, this would indicate that it may primarily be conceptual strengthening that leads to later interference. The most compelling support can be drawn from Experiments 3C and 3D. Picture Matching, which did not require any lexical processing, engendered cumulative

facilitation across ordinal positions of related trials whereas generative picture naming (using the same targets) engendered cumulative interference. That is, interference was only observed when lexical retrieval and selection were engaged during the Final Assessment Task. This can be most clearly seen in Experiment 3C. Specifically, the nongenerative Learning Phase displayed cumulative facilitation, whereas the following picture naming Assessment Phase elicited cumulative interference. This finding holds regardless of whether items related to previously matched items exhibited heightened interference. The hypothesis that it is conceptual level facilitation that drives interference is inconsistent with the Norman et al. (2007) account of retrieval-driven learning, which posits that it is downregulatory processes acting on featural connectivity within concepts that drives interference. However, given that this model does not include lexical level processes or intermediary lexical concepts, the current iteration of the model may not be equipped to differentiate between the long term effects of conceptual strengthening and downregulation. This is a key question that must be addressed in the next generation of modeling and theorizing, and I will return to this issue in the General Discussion.

General Discussion

It is natural for a given discipline to become entrenched in their own idiosyncratic framings and methodologies; after all, it is this focused refinement that results in highly sophisticated theories and models. However, this focus necessarily excludes the equally valid approaches of adjacent literatures despite their underlying commonalities. The limitations of this exclusionary approach are readily apparent when comparing the study of semantic interference across memory and language production literatures, and integration of these two rich bodies of work is long overdue. The overarching goal of this dissertation was thus to develop an aligned account of conceptual-lexical retrieval and provide evidence that adopting an integrated

conceptual-lexical approach is necessary to fully understand the adaptive learning mechanisms proposed to underly semantic interference phenomena.

Semantic interference refers to the broad phenomenon that generating a representation from memory impairs later access to related representations. In the relevant memory literature, semantic interference is studied as "retrieval-induced forgetting," where generative memory retrieval impairs retrieval of related items at later test (e.g., Anderson et al., 1994). The prominent computational account by Norman et al. (2007) proposes that during generation, an adaptive learning mechanism weakens the intrafeatural connections within coactivated semantic competitors, thereby making these related items harder to access at final test. In this literature, only aggregate retrieval successes/failures are typically reported (but see Brown, 1981 for an early exception), and there is little finer-grained work focused on elucidating the by-trial learning processes that are thought to drive interference. In addition, and critically for the present purposes, the current perspectives completely neglect the role of lexical processes entrained by the word generation procedures that memory paradigms often employ.

In the largely separate language production literature, interference is routinely observed when naming semantically related pictures interspersed throughout an internally structured continuous sequence. One item per related set is presented in each sector of the sequence in order to assess the effect of each related retrieval. The typical observation is that picture naming latencies increase linearly across ordinal positions of related items (e.g., Howard et al., 2006). Errors are typically quite low, and they are rarely formally assessed. The preeminent computational model by Oppenheim et al. (2010) proposes that interference is due to weakened connective links between conceptual features and words. Thus, production models propose that

adaptive learning acts only on connections to lexical representations and fail to capture the richness of more dynamic models of conceptual knowledge.

Although the diverging methodologies prevent direct comparison of the respective outcomes, both fields observe the same basic behavioral phenomenon – generation of conceptual-lexical representations impairs access to semantically related representations. Moreover, the generative tasks employed by the two fields both entail conceptual-lexical retrieval and the pre-eminent computational accounts posit that an adaptive learning mechanism modulates accessibility to the same set of broader semantic representations, albeit at different levels. It is therefore a reasonable assumption that the two fields are studying different aspects of the same process. Critically, I suggest that a comprehensive understanding of semantic interference can only be gleaned from the synthesis of the two literatures. In the present dissertation, I developed an integrated framework to guide a series of empirical studies and inform future computational models.

Summary of Approach and Key Findings

The synthesis of the two literatures has not been a trivial undertaking. The process began with a thorough review of each literature, including a focused comparison of the pre-eminent computational models of adaptive learning in memory and language (Norman et al., 2007; Oppenheim et al., 2010). From this review, I developed an initial aligned framework (see *A Unified Framework : Blueprint for Future Models of Conceptual-Lexical Access*). This framework described the necessary components of a comprehensive incremental learning model of conceptual-lexical retrieval, areas where the memory and language production accounts were aligned, areas in which they diverged, and open questions (see Table1). The following

experimental components were designed to investigate these assumptions. The results of these components would then be used to inform the parameters of an updated framework.

The first component of the dissertation, *Retrieval-Induced Semantic Interference,* served as a proof of concept for the viability of this aligned framework. This experiment also developed a novel modification of the retrieval practice paradigm that served as the primary methodology for the dissertation. Specifically, I implemented the internally structured, latency-based approach from the language production literature within each phase of the retrieval practice paradigm and replaced the final test phase with a sequence of continuous picture naming. The first component thus sought to assess if the category-stem cueing typically used in the memory literature would result in hindered access to semantically related picture names.

In this integrative paradigm, participants were asked to recall a subset of familiarized items in response to category-stem cues (e.g., FRUIT – or___, "orange"). In this phase, I sought to investigate how downregulatory learning processes unfold across the Generation Phase and compare the pattern to the linear trajectory observed in the continuous picture naming paradigm. To accomplish this goal, the sequence was internally structured in the manner of a continuous naming experiment, such that participants generated related items evenly throughout the sequence. Changes in generation latencies over related ordinal positions indexed how accessibility changed within the phase. In order to assess the generality of interference, I used a sequence of continuous picture naming (instead of category-stem cueing) in the Final Assessment Phase and assessed both latencies and errors throughout the phase. The effect of past generation was assessed by comparing the naming latencies of pictures related to previously generated items (Activated condition) or unrelated controls (Control condition). In this way, this experiment also served as a test for the shared assumption of cue-independence. As discussed in

the *Unified Account*, both language production and memory models of retrieval-induced semantic interference assume that hindered access to related representations occurs regardless of the cue used to trigger retrieval. Thus using category-stem cueing in the Generation Phase and picture naming in the Final Assessment Phase served as a new way to investigate the shared claim of cue independence.

The results provided robust support for adopting an integrated perspective. In the Generation Phase, there was significant cumulative interference over ordinal positions of related items (primarily in the first repetition), replicating the pattern observed in the picture naming literature. In the critical Final Assessment Phase, there was a significant *retrieval-induced semantic interference effect*, in which pictures taxonomically related to previously generated items were named more slowly than Controls, but the difference between Activated and Control conditions was mitigated across ordinal positions. In addition, there was new cumulative interference for both conditions. That is, interference was observed as the result of both cross and intra-phase generative retrieval. These results thus underscore the value of using temporal analyses in each phase to disentangle the sources of interference, which are obscured by the aggregate measures used in the RIF literature. Moreover, they show that interference occurs despite the change in format and thus provide a new demonstration of cue independence. Most importantly, they also provide robust support for the benefits of assuming an integrative conceptual-lexical account of retrieval-driven semantic interference.

The second component of the dissertation, *Adaptive Learning After Semantic Interference: Does Interference Promote Enhanced Relearning?,* focused on exploring a particular claim in the memory literature through a language production lens. Specifically, this component examined the idea of *enhanced relearning* (also called "accelerated" relearning), in

which relearning recently punished competitors results in heightened accessibility in comparison to never-punished controls (Storm et al., 2008; Hulbert & Norman, 2015). Although neuroimaging evidence supports the role of neural differentiation during adaptive learning in promoting enhanced relearning, the current behavioral evidence is weak for existing semantic representations (i.e., Storm et al., 2008). The experiment design entailed a modified version of the integrated retrieval practice paradigm developed in Component 1. Specifically, a generative "Relearning" phase containing a subset of categories occurred prior to the Final Assessment Phase (see Storm et al., 2008). In this phase, participants generated items in response to category-stem cues and were then presented with the corresponding picture and name. Thus, Activated and Control conditions were compared under typical (baseline) RIF procedures as well as when Activated items (plus Controls) underwent relearning prior to assessment. This design mirrored that of previous work (Storm et al., 2008; Hulbert & Norman, 2015; Storm & Soares, 2022) with two key exceptions.

First, in an effort to produce more robust behavioral results than those of Storm et al. (2008), I used category-stem cue generation followed by refamiliarization in the Relearning phase to promote deeper relearning processes. Second, I again used continuous picture naming in place of category-stem cue generation in the final phase. These manipulations thus allowed me to examine the temporal dynamics of relearning following downregulation, as well as assess if relearning was enhanced for recently punished conceptual-lexical representations. In the Generation Phase, I again found cumulative interference during category stem-cued generation, replicating Component 1. In the following Relearning Phase (which has not been previously dissected), cumulative interference also occurred. Descriptively, there was a pattern of hindered access in the Activated condition relative to Control, but this difference was not significant and

vanished completely over Repetitions. Although the RIF pattern was not statistically significant in these data, it illustrates how the procedure can in principle reveal how relearning erases previous semantic interference even as new interference accrues. In the Final Assessment Phase, I again observed overall cumulative interference, and replicated the significant cost in naming the Activated condition relative to Controls in the Baseline condition. However, there was no benefit in naming Generated ("relearned") Activated items relative to Generated-Controls. That is, there was no evidence of enhanced relearning. Recall that the most robust support for enhanced relearning was found by Hulbert & Norman (2015), who used novel pairs of names and pictures. The original work by Storm et al. (2008), which used taxonomic relations, only found marginal evidence of enhanced relearning. In addition, their follow up work (which also used taxonomic relations) found that relearning erased interference effects but did not enhance access to punished competitors relative to controls (Storm & Soares, 2022). The present results thus directly replicate this latter finding and demonstrate that enhanced relearning may simply not occur for taxonomic relations. Rather, the current body of evidence suggests that while relearning may make recently punished competitors hyper accessible in a novel learning context, this benefit does not apply to well established conceptual-lexical networks. This supposition imposes constraints on the generality of differentiation processes in memory, such as those proposed in the Nonmonotonic Plasticity Hypothesis of Ritvo et al. (2019). The differentiation processes thought to drive enhanced relearning in the nonmonotonic plasticity framework are thought to occur during moderate levels of coactivation across memory systems (Ritvo et al., 2019). This is inconsistent with the results of Component 2. If coactivation were enough to cause long term interference, then differentiation processes should have also occurred. These results

thus suggest that competition driven differentiation may not occur in conceptual-lexical adaptive learning (Ritvo et al., 2019).

The final component of the dissertation, *Durability and Locus of Semantic Interference***,** sought to tackle two fundamental issues in the development of an integrated account of conceptual-lexical adaptive learning. This component examined both the locus of interference within the conceptual-lexical network and the claim of temporal durability assumed by both literatures. This component comprised four sub-experiments, two (3A and 3B) centered on the question of duration of interference and two (3C and 3D) focused on the locus. Experiments 3A and 3B used the same multi-phase retrieval practice design as in Component 1 but used a single-pass continuous picture naming task in both Generation and Final Assessment Phases. Critically, the retention interval between these phases was either short (15 minutes, Experiment 3A) or long (up to a full day and including nocturnal sleep, Experiment 3B). Experiment 3A showed cumulative interference in each phase (as expected), but unexpectedly did not show a significant retrieval-induced semantic interference effect across phases. This is especially surprising given the robust interference observed when category-stem cues were used in the Generation Phase of the previous two components. The same pattern was shown in the long retention interval latencies (Experiment 3B), but here there was some support of a long duration effect in errors (significantly more errors in the Activated condition relative to Controls). Thus, with a methodology closer to the typical implementation of the continuous picture naming paradigm, I only observed more erroneous naming following nocturnal sleep. This provides tentative evidence in favor of the role of sleep-based consolidation processes. However, this effect was not found in latencies. Given the change in format in Component 3, this may suggest that overt category labels and repetitions enhance interference. Alternatively, the accumulated interference

in the Generation Phase may simply not have been robust enough to promote long term interference. This work should thus be replicated to more conclusively address the issue of durability.

Experiments 3C and 3D both used a non-lexical task during the Generation phase with the aim of eliciting conceptually based adaptive learning. If retrieval-induced semantic interference reflects primarily conceptual-level adaptive learning as assumed in most of the memory literature, one should observe interference even when lexical processes are not explicitly engaged. These experiments used a novel picture matching task in the Generation Phase, in which participants matched an associatively related picture to one of four taxonomic relatives. That is, participants performed the matching task on the same taxonomic picture targets that are named in the previous generative picture naming design. As in the preceding experiments, related trials were internally organized across structured quartiles.

I first conducted a pilot study to benchmark this picture matching task. Surprisingly, I observed cumulative facilitation across ordinal positions, suggesting that when lexical processes are not recruited, interference does not occur. In hindsight, the outcome is consistent with the work of Belke (2013), who found cumulative interference in continuous picture naming but cumulative facilitation in continuous picture categorization. She posited that nongenerative tasks (such as categorization) strengthened the connections between features and lexical concepts, whereas semantic interference in a generative context is due to *weakened* links between features and lexical concepts. Moreover, she posited that if conceptual learning processes strengthen the coactivation of taxonomically related items, such facilitation could promote heightened interference when translated to a generative context.

To further examine this hypothesis, Experiment 3C used the pre-lexical picture matching task in the initial Learning Phase and generative picture naming in the Final Assessment Phase. I replicated the cumulative facilitation across ordinal positions in the initial (picture matching) Learning Phase. In the Final Assessment Phase, there was overall cumulative interference, but no significant difference in naming latencies between the Activated and Control conditions (although there were marginally more errors). This suggests that although the engagement of lexical processes did result in cumulative interference effects, there was no long-term effect of previous related picture matching on this process. This is contrary to predictions and may suggest that although cumulative facilitation was observed in the Learning Phase, it was not robust enough to promote long term heightened coactivation of taxonomic relatives in the later Assessment Phase.

Given these results, Experiment 3D sought to test the inverse claim that, when in the same nongenerative context, cumulative facilitation should enhance related picture matching performance relative to unrelated controls in the Final Assessment Phase. I again showed cumulative facilitation in the initial Picture Matching Phase. However, there was no significant cumulative effect in the Final Assessment (Matching) Phase nor any significant difference between Activated and Control conditions. The lack of matching-induced facilitation for related pictures was inconsistent with my predictions. This may again suggest that the cumulative facilitation observed in the Learning Phase is not robust, or alternatively, that the facilitation was the result of methodological factors rather than conceptual adaptive learning. Yet, the opposite directionality of cumulative effects in lexical versus pre-lexical tasks suggests that lexical generation is necessary to observe interference (Belke, 2013). Moreover, the pattern of cumulative facilitation observed in the pre-lexical picture matching task may suggest that when

lexical generation is not engaged, conceptual level adaptive learning may be primarily facilitative. Together, the results from this component call for more focused investigations into the durability of retrieval-driven semantic interference and suggest that conceptual-level adaptation may only manifest as interference when language production is involved.

Implications for Key Accounts of Conceptual-Lexical Retrieval

The experiments reported here were conceived within an integrative language-memory approach to conceptual-lexical retrieval and semantic interference. Collectively, the experiments show that combining memory and language production methodologies provides much more richly informative data than that provided by either alone, and that investigating the hypotheses of one field through the lens of the other can clarify overlapping areas of the two literatures. These experiments are only the first initial steps toward the broader goal of integration, and much work remains to be done to enrich our understanding of conceptual-lexical adaptive learning. Spanning the experiments, several key findings emerged that call for the development of new, broader models of conceptual-lexical retrieval.

New Evidence of Cue Independence

The assumption of cue independence, as initially suggested by Anderson & Spellman (1995), posits that retrieval-induced interference for items related to previously generated items occurs regardless of the cue used to trigger later retrieval. However, there has been some research that questions this assumption (e.g., Perfect et al., 2004; Jonkers et al., 2013), and it remains an active debate in the RIF literature. I thus assessed this shared claim in Component 1 by using category-stem cueing in the Generation Phase and picture cues in the Final Assessment Phase.

Components 1 and 2 found robust cumulative interference (as observed in many language production experiments) with the category-stem cueing typically used in memory studies. Critically, these components also found that, in the Final Assessment Phase, it was more difficult to name pictures related to previously generated category-stem cues. Thus, interference was observed despite the change from category-stem cueing to picture naming across phases. This cue independence is assumed by both memory and language production literatures but can be difficult to assess with the typical implementation of the retrieval practice paradigm (see Jonker et al., 2013). Using pictures as self-contained cues in the Final Assessment Phase provides a new way to test the assumption of cue independence within and across the two literatures.

The results of Component 3 may challenge this interpretation. In Component 3 (A & B), I failed to find a significant retrieval-induced semantic interference effect with a single pass of generative picture naming in the Generation Phase. How does one reconcile this null finding with the cumulative interference found within each phase, and with the significant retrieval-induced semantic interference found when using category-stem cues during the Generation Phase?

First, I note that the cumulative interference observed in the Generation Phases of Experiments 3A (OP_4 - OP_1=45 ms) and 3B (46 ms) was indeed significant, but it was not as robust as that observed in Components 1 (182 ms) or 2 (239 ms). It is possible that this was due to methodological changes across the components. Recall that the procedures of Components 1 and 2 (which used category-stem cue generation) and Components 3A and 3B (generative picture naming) differed in several key regards. In the initial Familiarization sequence of Components 1 and 2, pictures were presented with both their category label and name. Then, during the Generation Phase of Components 3A and 3B, category labels and stems were used to

trigger retrieval, and each item was cued three times (across three internally segmented, reshuffled continuous sequences). In addition, in the following Final Assessment Phase of these experiments, the category of each upcoming picture was presented quickly before the presentation of each picture target. In contrast, in experiments 3A and 3B, pictures were only presented with their name in the initial Familiarization sequence. In both the Generation and Final Assessment Phases, picture targets were presented without category labeling in a single continuous sequence.

Thus in Experiments 3A and 3B, semantic relatedness was established by intrinsic feature overlap without any overtly encoded label linking taxonomically related representations. This is the typical implementation of the continuous naming paradigm. Past work in our lab has found more robust cumulative interference (i.e., 156s ms; O'Séaghdha et al., in prep) using the same procedure (albeit with more items), so it remains possible that the lack of long term effects is due to either insufficient power or to the additive role of explicitly encoded shared category cues. The present work is not capable of disentangling these two possible contributions, but future work should seek to replicate this finding with a more powerful design.

Relearning is Not Enhanced in Conceptual-Lexical Adaptation

Component 2 tested whether interference results in enhanced relearning of previously downregulated conceptual-lexical representations. Enhanced relearning has been attributed to neural differentiation, a process in which the patterns of semantically related representations are made more distinct (Hulbert & Norman, 2015; Ritvo et al., 2019). The strongest evidence in favor of enhanced relearning has been found in neuroimaging studies using novel combinations of images that engaged episodic learning (Hulbert & Norman, 2015; Favila et al., 2016; Schlichting et al., 2015). In contrast, Storm et al. (2008) and Storm and Soares (2022), who used

intrinsic taxonomic relatedness, found marginal or no evidence of interference boosting later accessibility. In line with this memory retrieval work, I failed to find evidence of enhanced relearning for previously downregulated representations. These collective null results constrain the applicability of the recent Nonmonotonic Plasticity account, which posits that differentiation is a pervasive characteristic of (moderate) coactivation across both episodic and semantic memory systems (Ritvo et al., 2019; Ritvo et al., 2024). The present results challenge this assumption and instead suggest that enhanced relearning (and by extension the differentiation proposed by Ritvo et al.) does not occur for retrieval of familiar conceptual-lexical representations from a well-learned semantic network.

Durability of Interference

Both literatures also claim that interference effects are quite durable. Specifically, Oppenheim et al. (2010) proposed that interference dissipates with relevant generation experience, but not time. However, there has been little to no direct tests of this claim in the context of continuous picture naming (but see Schnur, 2014). In the RIF literature, interference is also proposed to be long-lasting, with some studies observing interference effects up to a week after the initial Generation Phase (Storm et al., 2012; Tandoh & Naja, 2007). Others posit that sleep-based consolidation processes are necessary to preserve the downregulation of related items (Abel and Bäuml, 2012, but see MacLeod & McRae, 2001). The language acquisition and comprehension literatures have also supported the stabilizing role of sleep (e.g., Gaskell et al., 2019; Hulme & Rodd, 2023), but little work has examined how sleep shapes access to pre-existing conceptual-lexical representations in a production context.

The current findings regarding the durability of semantic interference are somewhat mixed. In the first Component, I found significant retrieval-induced forgetting when a 15-minute

retention interval separated the Generation and Assessment Phases. However, in Component 2, the pattern of hindered access to Activated items relative to Controls was not significant in the Relearning Phase. However, it was present after a longer delay for Baseline items in the following Phase. In addition, in Experiment 3A, which essentially comprised a single continuous sequence cut in half (with an added control condition) and separated by a 15-minuite lag, there was no difference in naming (latencies) for the Activated and Control Conditions. This latter finding is inconsistent with the claim of temporal insensitivity proposed by Oppenheim et al. (2010) and assumed by Norman et al. (2007). I note that this claim has been previously questioned by Schnur (2014), who found that cumulative interference in picture naming was weaker when more than eight unrelated pictures separated category members. However, the present work in turn challenges this finding since I did find stable intraphase cumulative interference when the lag could be up to 16 unrelated items. Further complicating this issue, Component 3B found greater error rates in the Activated condition during the Final Assessment Phase, suggesting that sleep-based consolidation processes may aid in preserving recent adaptations within the conceptual-lexical network. Specifically, it is possible that consolidation processes reconstructed the downregulation of words that were coactivated but not selected in the Generation phase, thus making these words less accessible in the following Final Assessment Phase. Thus, much more work is needed to clarify the durability of interference.

Origin and Locus of Retrieval-Induced Semantic Interference

Component 3 sought to elucidate the relative contributions of conceptual and conceptual-lexical adaptive learning in retrieval-induced semantic interference. I found that picture matching, which does not directly engage lexical processes, elicited cumulative facilitation. This facilitation was sharply contrasted by the significant cumulative interference in generative tasks

throughout the dissertation, including in the Final Assessment Phase of Experiment 3C. This suggests that interference only occurs when lexical retrieval and selection are required by a task (Belke, 2013; see also Belke, 2005). These findings are in line with a series of studies by Belke (2013), who sought to identify the origin of semantic interference effects. She observed cumulative interference in generative picture naming, but found cumulative facilitation with a continuous object classification task (using the same targets) that did not entail production processes (see also Döring et al., 2022). Based on these findings, she concluded that semantic interference originates from conceptual level processing, and net interference effects only occur when lexical retrieval is engaged. Although the present study used a novel iteration of a picture matching methodology to approximate pre-lexical conceptual processing, the results are consistent with this general proposal. I will return to this issue shortly.

A Framework for Future Work

In the earlier section, *A Unified Framework: Blueprint for Future Models of Conceptual-Lexical Access,* I laid out a sketch for a future integrated model of conceptual-lexical retrieval. I began by listing some key characteristics that an integrated model must contain to comprehensively capture cross-field retrieval-induced semantic interference phenomena. I then listed a number of theoretical assumptions held by both fields as well as those that were unaligned (see Table 1). The goal of the experimental components that followed this integrative blueprint was to test specific tenets of the aligned framework. Specifically, this work aimed to confirm the necessary model components outlined earlier and validate that the aligned assumptions hold true in an integrative conceptual-lexical context. The experiments also aimed to clarify diverging views and inform currently open questions. I note that this work only tested a handful of questions. Thus, the work reported here constitutes only a few initial steps towards the

broader goal of integration. Direct computational implementation of a working model is beyond the scope of this dissertation, but here I offer an update to the verbal integrated incremental learning model described earlier.

Model Architecture

In the earlier description of the aligned framework, I laid out some initial recommendations for what a comprehensive model of conceptual-lexical retrieval must include. Here, I offer an update to those recommendations based on the present findings. An updated version of the integrated account of incremental learning can be seen in Figure 16.

I previously asserted that a comprehensive model must contain distributed semantic features and explicit lexical representations. Unsurprisingly, this position is retained in light of the present findings. Recall that in Norman et al. (2007), the semantic ("cortical") network is comprised of separate but fully connected "associate" (i.e., category) and "item" (i.e., exemplar) layers of representation (see earlier section, *Two Influential Computational Accounts*). This method of representation was implemented for practical reasons and does not reflect the single shared store of conceptual features thought to underly semantic memory (see Kumar, 2021 for review). Also recall that the Oppenheim et al. (2010) model includes a small number of features and lemmas (20 semantic features and 50 words) that does not even begin to approximate a naturalistic lexicon. I suggest that future models should avoid over-specification to any given task to improve the generality of simulations. In addition, future models should also strive to drastically expand the number of both features and words. Given recent strides in large language models (e.g., Trott et al., 2023), a working model might be derived from a subset of a broader trained architecture.

I also propose to augment computational power by including a hidden layer between conceptual features and lemmas,. This proposal is largely consistent with ideas outlined in O'Séaghdha et al. (in prep). In this account, which includes a scaled-up library of both semantic features and words, a hidden layer can engage "implied" semantic features not explicitly input into the system, thereby allowing features not directly shared by the competitor and target to dynamically affect adaptive learning processes. This is different from the implementation of Oppenheim et al., (2010), in which only the connections to shared features are modulated. However, this *is* in line with Norman et al. (2007), in which the connectivity to any feature that is overactive (regardless of whether or not it is shared by the target) is subject to downregulation. This hidden layer may also (at least partly) capture the functionality of (amodal) lexical concepts (Belke, 2013; Vigliocco et al., 2004). I will return to this issue shortly.

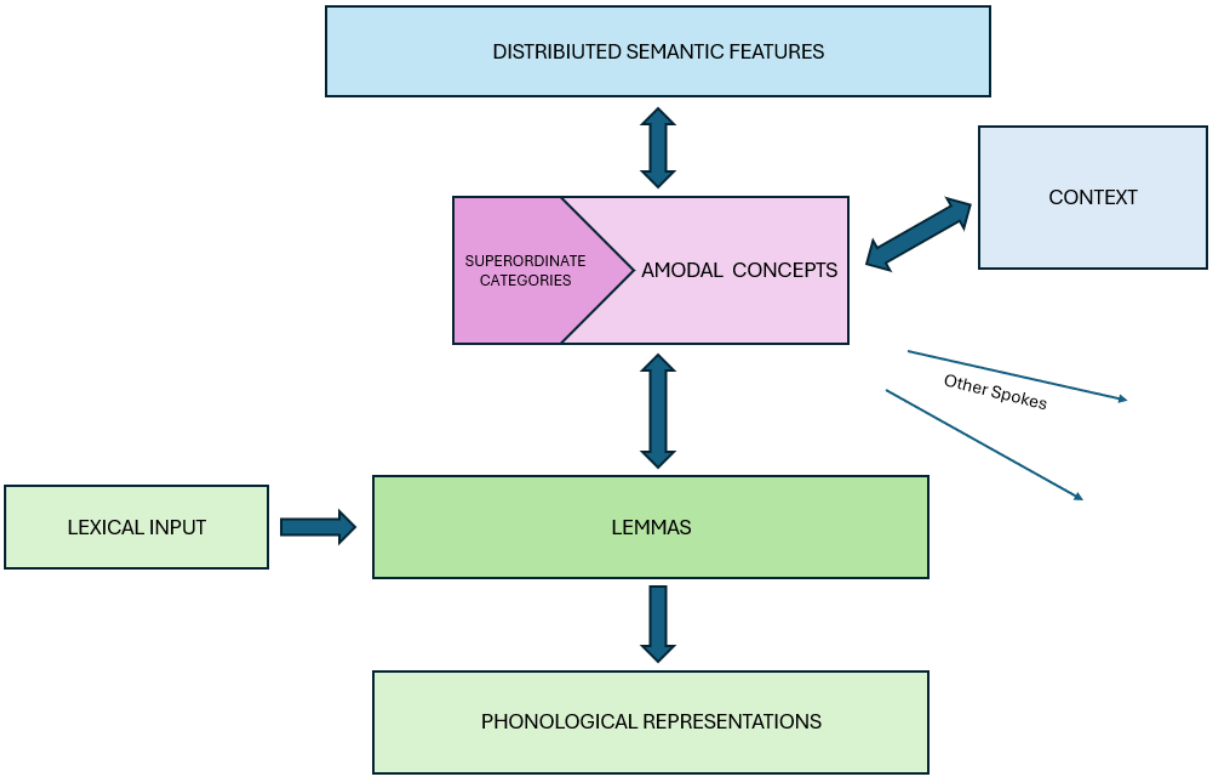

Figure 16. Tentative sketch of the required components of an integrated model of conceptual-lexical retrieval. A multilayered network is comprised of semantic features, an integrative hidden layer (amodal concepts), and lemmas. Lexical stems or whole words may contribute to lemma activation, and phonological representations of words are output from lemmas. A possible learning architecture could entail conceptual adaptive learning that is primarily facilitative and conceptual-lexical learning that is primarily punitive.

Future models should also be able to simulate a wide variety of tasks, including category-stem cueing, picture naming, and categorization. In order to do so, future models must include a way to input both lexical stems and superordinate category labels. While Noman et al. (2007) does include a (redundant) associate layer to represent the presentation of a given category, Oppenheim et al. (2010) does not represent overarching superordinate categories. In addition to the work in memory highlighting the possible importance of shared cues (e.g., Perfect et al., 2004), past work in language production has shown that other types of relatedness, such as thematic relations, may be heavily mediated by the comprehension of linking superordinate labels (e.g., Abdel Rahman & Melinger, 2011). Given the simulation requirements and that overt comprehension of a shared category label may modulate learning in different contexts (see also Dirani & Pylkkänen, 2023), these higher-level relations should be included in future models. More work is needed to determine if a single layer of semantic feature representation with added intermediary (hidden) layer(s) could economically and dynamically capture these multileveled semantic representations.

I also note that Norman et al. (2007) has a distinct "context" layer, which is used to bind together the current pattern of semantic activation with the current coactive environmental context, thereby creating an episodic "tag" for each retrieved representation. In conjunction with the broader episodic ("hippocampal") layer, this context layer captures the role of episodic memory processes on top of intrinsic semantic relatedness. Interestingly, the recent iteration of the Dark Side Model (Oppenheim & Nozari, 2024) also includes a "context" layer, though it is different than that implemented by Norman et al. Rather, the context layer of Oppenheim & Nozari (2024) served to model the context dependency of thematic coactivation. In both cases, the added layer representing the surrounding context augments the models of conceptual-lexical

retrieval. Specifically, integrating the recurrent activation implemented in Oppenheim & Nozari (2024) and the environmental tagging capabilities of Norman et al.'s (2007) may aid in capturing the dynamics of relations beyond taxonomic categories as well as novel learning episodes.

Model Dynamics

At the outset, I assumed that an integrative model of conceptual-lexical retrieval would primarily serve to simulate semantic interference phenomena. However, the results of Component 3 demonstrate that a comprehensive model must be able to account for both pre-lexical cumulative facilitation as well as cumulative interference in (lexical) generation.

First, recall that Belke (2013) suggests that it is adaptation at the conceptual level that drives retrieval-driven interference, even if it is only expressed through the locus of lexical retrieval and selection. In Norman et al. (2007), long-term interference is due to weakened featural links within competing conceptual representations, while the conceptual-level learning in Belke (2013) is conceptualized as modulated links between shared features and competing lexical concepts. Belke (2013) suggests that this learning mechanism could be similar to that proposed to act on conceptual-lexical links in Oppenheim et al. (2010), in which links can either be strengthened or weakened under different conditions. In contrast to her working model, I suggest that the findings of pre-lexical cumulative facilitation in the present picture matching task (which required the selection, but not generation, of individual items) and the generative cumulative interference found in picture naming suggest that two distinct levels of modulation are necessary to account for both effects.

Specifically, I suggest that a model which includes conceptual (feature-lexical concept) strengthening and weakened conceptual-lexical connections (between lexical concepts and lemmas) could produce both effects. In such a model, conceptual retrieval would strengthen the

links between activated features and lexical concepts, such that recurrent retrieval of semantically related items would promote heightened coactivation among category members. When lexical retrieval occurs, the links between coactivated concepts and lemmas would be weakened to the extent that they were overly activated.

For example, say one generates the target *moth.* The links between the features *six legs* and *antennae* and the lexical concept *moth* would be strengthened, as well as the links between these features and the coactivated related concept *cricket*. If *cricket* is later cued in a pre-lexical task, such as matching, the strengthened connections between the concept *cricket* and relevant semantic features would speed matching. However, in the context of a generative task, the concept *moth* activates the lemmas of both *moth* and *cricket*. Since only a single word can be produced, this coactivation is inherently problematic. The competing word could be downregulated by weakening the connective link between the amodal concept *cricket* and its respective lemma. Thus, if *cricket* is presented for picture name generation, the weakened conceptual-lexical links would slow production. Such a model would thus predict that related pre-lexical conceptual retrieval would be facilitative (due to strengthened featural connections), but that this conceptual facilitation would result in interference when the target must be spoken.

How long these adaptations last is somewhat unclear. If interference resulting from generative picture naming is less durable than the interference that accrues in category-stem completion (as could be concluded by the results of Component 3), it is possible that adaptations to connective weights may differentially decay across time. This could be modeled by including a decay parameter in which connections return to starting weights after a given time period or after experiencing a given degree of random noise in the network. Based on the tenuous support of nocturnal sleep preserving hindered access to coactivated competitors reported here, as well as

the evidence provided by the broader sleep literature, it is possible that sleep-based consolidation may play a role in maintaining long term adaptive learning. Specifically, it is possible that consolidation processes re-instantiate prior network states through reactivation of recently encountered conceptual-lexical representations.

Open Questions and Future Directions

As the present work is only some initial steps towards integration of memory and language production accounts of conceptual-lexical retrieval, there are several questions that need to be addressed to clarify the details of an integrated account. A series of exploratory models could be developed in conjunction with ongoing experimental work to address these questions and constrain interpretations.

One issue that warrants further investigation pertains to the shared claim of durability. In Component 3, I failed to find significant retrieval-induced semantic interference after 15-minutes when using a single pass of picture naming. It is possible that significant long-term effects were not observed due to the brevity of the initial Generation Phase, which only entailed one presentation of 20 pictures. Given the limited work currently available in both literatures, much more work is needed to assess the temporal parameters of interference. For example, highly-powered studies with finer-grained manipulations in retention intervals (e.g., 5 or 10 minutes compared to a 0 minute control) could provide insight into the possible decay of interference, and sleep manipulations with diurnal controls would provide additional insight into the role of sleep based consolidation processes.

The most critical open area is more theoretical. Specifically, it remains unclear where exactly the adaptive learning thought to drive retrieval-driven semantic interference takes place. Although I found cumulative interference using a category-stem procedure, it is not possible to

disentangle the role of lexical retrieval from conceptual-level learning in this task. Rather, the clearest evidence regarding the question of origin can be seen in Component 3, where I observed cumulative facilitation in a non-generative picture matching task, but cumulative interference shortly afterward when target names were generated in a continuous sequence. Earlier, I suggested that these findings may be best accounted for by a model that strengthens the connections between features and lexical concepts and weakens connections between concepts and lemmas.

However, more work is needed to clarify the distinct contribution and underlying nature of lexical concepts. Belke (2013) integrated the conceptualization of lexical concepts from Levelt et al. (1999) and the FUSS model (e.g., Vigliocco et al., 2004; Vinson & Vigliocco, 2002). The FUSS model posits that semantic representation entails both modality-specific semantic features and unitary amodal conceptual representations. The distinction between holistic amodal concepts and modality-specific features is also emphasized in the "hub and spoke" model of semantic memory (Rogers et al., 2004; Patterson & Lambon-Ralph, 2016; see Patterson et al., 2007 for review). In this framework, diverse regions of the cortex are responsible for processing modality-specific semantic information, and this information is linked and integrated in an amodal fashion in the anterior temporal lobe. This type of model has been influential in the study of semantic memory and the presence of an amodal semantic hub has been supported by a wealth of clinical data (e.g., Hoffman & Lambon-Ralph, 2011; Patterson & Lambon-Ralph, 2016). Wei & Schnur (2016) proposed that such a model could be adapted to include adjustable links between features and amodal concepts and between the amodal concepts themselves. It is also notable that the hub and spoke model includes an explicit "spoke" for the lexicon. It is possible that the current body of work could be captured by spreading activation

processes in the amodal hub and adjusted weights between amodal nodes and lexical representations. Future models of conceptual-lexical retrieval could thus aim to be integrated into broader hub-and-spoke models of semantic memory (Patterson et al., 2007).

Conclusions

This dissertation sought to bridge the study of conceptual-lexical retrieval that is currently fractured across memory and language production literatures. After a careful review of the literature, I developed a working framework that aligned the theoretical assumptions of the preeminent computational models of semantic interference in each field. The following empirical work was comprised of three components, each of which centered on investigating specific aspects of the aligned framework. The first component showed that memory measures elicited the same cumulative interference observed in the language production literature. Moreover, this generative experience hindered access to semantically related picture names in the following phase, showing that retrieval-induced semantic interference is evident in picture naming latencies. In Component 2, I tested the memory literature concept of enhanced relearning, which posits that interference can serve as a catalyst for more robust learning. I did not find any evidence of enhanced relearning in conceptual-lexical access, thus providing important caveats to modern memory accounts of competition-driven differentiation (Ritvo et al., 2019). In Component 3, I did not find any retrieval-induced costs to latencies with two phases of picture naming separated by a 15-minute or overnight retention interval, calling for more direct tests of the current claims of temporal insensitivity across fields. In this Component, I also found that a non-generative continuous picture matching task manifested cumulative facilitation rather than interference. This unexpected finding suggests that conceptual adaptive learning may primarily entail strengthening, while generative processes entail downregulation of competing

lexical representations. Together, these findings confirm that the isolation of memory and language production literatures is no longer justifiable. Moreover, they demonstrate the utility of the aligned framework proposed here and suggest that it could serve as a key guide for future empirical and modeling work. The study of semantic interference must be integrated, and expanded, integrative models must be developed to understand conceptual-lexical retrieval in its entirety.

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Appendix A

Materials for Component 1

Clothing: *shirt, belt, sock, jeans, scarf, boot, tie, hat*

Kitchen Utensils: *fork, cup, plate, whisk, knife, bowl, spoon, tongs*

Birds: *parrot, eagle, owl, seagull, flamingo, duck, pigeon, bluejay*

Fruit: *orange, pear, cherry, apple, banana, strawberry, lemon, grapes*

Mammals: *fox, squirrel, giraffe, skunk, zebra, elephant, moose, rabbit*

Body Parts: *arm, nose, lips, ear, elbow, hand, eye, knee*

Office Supplies: *envelope, ruler, eraser, pencil, marker, binder, stapler, chalk*

Tools: *axe, hammer, shovel, chainsaw, pliers, wrench, rake, screwdriver*

Instruments: *violin, piano, saxophone, drums, guitar, banjo, harmonica, trumpet*

Vegetables: *carrot, broccoli, potato, onion, celery, cucumber, eggplant, lettuce*

Appendix B

Materials for Component 2

Clothing: *shirt, belt, sock, jeans, scarf, boot, tie, hat*

Kitchen Utensils: *fork, cup, plate, whisk, knife, bowl, spoon, tongs*

Birds: *parrot, eagle, owl, seagull, flamingo, duck, pigeon, bluejay*

Fruit: *orange, pear, cherry, apple, banana, strawberry, lemon, grapes*

Mammals: *fox, squirrel, giraffe, skunk, zebra, elephant, moose, rabbit*

Body Parts: *arm, nose, lips, ear, elbow, hand, eye, knee*

Office Supplies: *envelope, ruler, eraser, pencil, marker, binder, stapler, chalk*

Tools: *axe, hammer, shovel, chainsaw, pliers, wrench, rake, screwdriver*

Instruments: *violin, piano, saxophone, drums, guitar, banjo, harmonica, trumpet*

Vegetables: *carrot, broccoli, potato, onion, celery, cucumber, eggplant, lettuce*

Vehicles: *boat, car, helicopter, jeep, truck, plane, bike, scooter*

Furniture: *chair, table, bed, shelf, desk, stool, dresser, lamp*

Appendix C

Materials for Component 3

Kitchen Utensils: *peeler (potato), tongs (salad), spoon (soup), plate (napkin), knife (cutting board), corkscrew (wine), cup (coffee), whisk (egg)*

Birds: *parrot (cage), eagle (flag), owl (moon), seagull (sea), turkey (Thanksgiving dinner), duck (pond), pigeon (statue), dove (olive branch)*

Fruit: *orange (Florida), watermelon (picnic), coconut (beach), apple (cider), blackberry (thorns), cherry (sundae), lemon (lemonade), grapes (vineyard)*

Mammals: *cat (yarn), dog (bone), monkey (banana), bear (honey), rabbit (carrot), squirrel (acorn), elephant (circus), cow (milk)*

Office Supplies: *envelope (letter), protractor (calculator), chalk (blackboard), pencil (eraser), stapler (staples), binder (hole punch), folder (cabinet), marker (whiteboard)*

Tools: *wrench (screw), hammer (nail), scissors (paper), axe (tree), pliers (wire), shovel (soil), drill (tooth), rake (leaves)*

Body Parts: *nose (tissues), lips (lipstick), eye (glasses), ear (headphones), leg (jeans), foot (shoes), hand (ring), neck (scarf)*

People: *waiter (menu), doctor (stethoscope), cowboy (lasso), photographer (lens), firefighter (hose), police (handcuffs), referee (whistle), chef (stove)*

Vehicles: *bike (basket), car (gas station), train (railroad), bus (bus stop), plane (sky), boat (anchor), truck (boxes), scooter (helmet)*

Furniture: *chair (seat cushion), table (tablecloth), crib (baby), lamp (light bulb), shelf (books), dresser (clothes), bed (duvet), bench (park)*

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PUBLICATIONS

Hambric, C. E., & O'Séaghdha, P. G. (2023). The unseen, the seen, and the spoken: Latent and overt priming in cyclic picture naming. *Quarterly Journal of Experimental Psychology*, 76(10), 2410–2430. https://doi.org/10.1177/17470218221144460.

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Marvel, C. J., Bates, J. E., Hambric, C. E., Braun, D. A., Arrington, C. A., & Harmer, M. P. (2021). The Lehigh Presidential Nano-Human Interface Project: Convergence of Materials, Computer, and Cognitive Science. *Materials Research Society Bulletin,* 46*,* 1-5.

Thrash, T. M., Wadsworth, L. M., Sim, Y. Y., Wan, X., & Everidge, C. (2019). Implicit–Explicit Motive Congruence and Moderating Factors. In *The Oxford Handbook of Human Motivation*.

Articles in Preparation

Hambric, C. E. & O'Séaghdha , P. G. (under revision). Retrieval-Induced Semantic Interference.

Hambric, C. E. (under review). *Adaptive Learning After Semantic Interference: Does Interference Promote Enhanced Relearning?*

O'Séaghdha, P. G., Hambric, C. E., Hupbach, A., Heflin, J. (in preparation). Task Specificity of Semantic Interference Effects in Production.

O'Séaghdha, P. G., Frazer, A., & Hambric, C.E. (in preparation). Preparation As a Mirror of Production: An Attentional Account of Phonological Preparation in Speaking.

Chen, M., Hambric, C. E., O'Séaghdha, P. G. (in preparation). Phonemes and Features: Insights from Form Preparation

PRESENTATIONS

Chen, M., Hambric, C. E., O'Séaghdha, P. G. (November, 2023). Phonemic Similarity in Production and Preparation: Is Place of Articulation Privileged? Poster presented at the 64th Annual Meeting of the Psychonomic Society.

Hambric, C. E., O'Séaghdha, P. G. (November, 2022). Aligning Language and Memory Accounts of Semantic Interference. Talk presented at the 63rd Annual Meeting of the Psychonomic Society.

Hambric, C. E. & O'Seaghdha, P. G. (July, 2022). Aligning Language and Memory Accounts of Semantic Interference. Flash Talk presented at the 44th Annual Meeting of the Cognitive Science Society.

Hambric, C. E., O'Séaghdha, P. G. (June, 2022). Aligning Language Production and Memory Accounts of Semantic Interference. Poster presented at the 12th International Workshop on Language Production.

LaMena, G., Rosano, D., Hallagan, N., Hambric, C. (April, 2022). Boosting Semantic Interference for Thematically Related Words. Poster presented at the 36th Annual LVAIC Undergraduate Psychology Conference.

Hambric, C. E., O'Séaghdha, P. G. (November, 2021). Solving the Problem of Cyclic Naming. Poster presented at the 62nd Annual Meeting of the Psychonomic Society.

Hambric, C. E., O'Séaghdha, P. G. (November, 2020). Overt and Latent Semantic Competition in Picture Naming. Poster presented at the 61st Annual Meeting of the Psychonomic Society.

Hambric, C. E., O'Séaghdha, P. G., Hupbach, A., Heflin, J. (March, 2020). Context Specificity of Semantic Interference Effects in Production. Poster presented at the 33rd Annual CUNY Sentence Processing Conference.

O'Séaghdha, P. G., **Hambric, C. E.,** Hupbach, A., Heflin, J. (November, 2019). Cross-Task Semantic Interference. Poster presented at the 60th Annual Meeting of the Psychonomic Society.

Miller, L., Lu, Y., Garcia, D., Haber, N., Everidge, C. (April, 2019). Subliminal Modulation of Semantic Interference. Poster presented at the 33rd Annual LVAIC Undergraduate Psychology Conference.

TEACHING EXPERIENCE

Cognitive Psychology, Primary Instructor (Summer Session II '21, '22, '23)
Cognitive Neuroscience Recitation, Primary Instructor (F'20)
Research Methods & Data Analysis I Lab Instructor (S'19, F'19)
Research Methods & Data Analysis III Lab Instructor (S'20, S'21, F'21)

Introduction to Linguistics, Teaching Assistant (F'18, F'22. F'23)
Research Methods & Data Analysis I, Teaching Assistant (S'19, F'19)
Research Methods & Data Analysis III, Teaching Assistant (S'20, S'21, F'21)
Cognitive Neuroscience, Teaching Assistant (F'20)
Introduction to Cognitive Science, Teaching Assistant (S'24)

AWARDS

CAS Graduate Student Research Prize (2023), *$500*
Doctoral Travel Grant for Global Opportunities (2019), *$500*
Dean's Semester Research Fellowship Award (Spring 2022), *RA Stipend*

PROFESSIONAL AND SERVICE ROLES

Representative to the Psychology Department Graduate Committee (2021-2022)
Graduate Student Representative to Lehigh University IRB (2019-2021)
Psychology Graduate Student Representative of the Lehigh University Advisory Committee for Research and Graduate Education (2020-2022)
Coordinator of Weekly "Brown Bag" Colloquia (2019-2020)
Graduate Student Coordinator of Participant Pool (2022-2023)
Nano/Human Interface Presidential Initiative – Research Assistant (2023-2024)

Peer Review – Journals:

Memory & Cognition
Psychonomic Bulletin & Review
Memory
Cognitive Science Society

PROFESSIONAL AFFILIATIONS

Psychonomic Society
Cognitive Science Society
Association for Psychological Science
Society for Human Sentence Processing
Women in Cognitive Science +

TECHNICAL SKILLS

E-Prime, R, SPSS, SONA, Some Python, Qualtrics, JASP, Microsoft Office, Google Applications