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Semantic interference in a randomized naming task: Effects of age, order, and category

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Abstract

Lexical retrieval in production is a competitive process, requiring activation of a target word from semantic input, and its selection from amongst co-activated items. Competitors are automatically primed through spreading activation within the lexicon, but competition may be increased by the prior presentation of related items, the semantic interference effect. This has been demonstrated in tasks in which pictures grouped by semantic category are compared to unrelated pictures (blocked naming) and in tasks involving successive naming of items from the same semantic category (continuous naming). Such highly structured tasks may not be representative of the processes at work under more natural word retrieval conditions. Therefore, we conducted a retrospective examination of naming latencies from a randomized picture naming task containing a wide variety of items and categories. Our large sample of adults, ranging in age from 22 to 89 years, also allowed us to test the hypothesis that older adults, who are particularly susceptible to word-retrieval problems, experience increased difficulty resolving competition among lexical items. Semantic interference effects were evident in the interaction between semantic category and order of presentation within a block—miscellaneous items were named more quickly, whereas related items were named more slowly. This interference effect did not vary with participant age, contrary to the hypothesis that older adults are more susceptible to semantic interference.

Keywords

word retrieval; lexical access; picture naming; aging; semantic interference

Introduction

Word retrieval in production requires that target words be activated and selected from among other concurrently active words, a process that may be influenced by a variety of internal and external factors. Internal factors include characteristics of the words themselves, relative to others in their surrounding lexical environment, as well as the efficiency with which lexical processes operate in a given individual. External factors include aspects of the task, such as the degree to which responses are constrained (Gordon & Kindred, 2011), or the presence or absence of competing demands on processing resources. In the current study, we retrospectively analyze picture naming data previously collected from adults varying in age, in order to determine the relative effects of individual differences, order of presentation, and semantic category on naming latencies. We focus particularly on the accumulation of

activation that is hypothesized to arise in continuous naming tasks, and how it may be affected by age.

Contemporary models of lexical access in speech production propose that activation cascades automatically from semantic representations of the intended message to corresponding lexical units, then on to phonological units. This cascade results in the co-activation of items sharing semantic features with the target item. Some models also postulate that activation spreads interactively, feeding back from phonological to lexical and lexical to semantic units (e.g. Dell, Schwartz, Martin, Saffran, & Gagnon, 1997). Thus, in the course of a word-retrieval attempt, many non-target items become active, and the system must incorporate some mechanism allowing it to quickly settle on the desired target. In tasks involving more than one word, this proliferation of activation is compounded; activation carried over from previously retrieved or activated words can interfere with subsequent targets. This is a problem that must be solved in natural discourse, of course, but experimental paradigms have helped to illustrate specific aspects of the interference problem.

Semantic Interference

One such task is the picture-word interference paradigm (Glaser & Dungelhoff, 1984), in which items to be named (usually pictures) are presented along with distractors (usually written words). Distractors which are categorically related to the target typically slow retrieval of the target's name (Damian & Bowers, 2003; Damian, Vigliocco, & Levelt, 2001). The standard interpretation of this effect is that it reflects a competition for selection between the lexical representations of the distractor and the target (Abdel Rahman & Melinger, 2009; Cooper Cutting & Ferreira, 1999; Roelofs, 1992; Wheeldon & Monsell, 1994), although an alternative proposal suggests that the lexical activation effects are only facilitative, and the interference arises at the stage of the articulatory buffer (Finkbeiner & Caramazza, 2006; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007; Miozza & Caramazza, 2003). Although there is considerable controversy about the locus of the effect, it is clear that the distractor's presentation interferes with retrieval of the target.

A related paradigm is semantic blocking, or blocked naming, in which single pictures are named in succession, but semantically related items are grouped together in a homogeneous block, and unrelated items are grouped in a heterogeneous block. Average naming latencies in homogeneous blocks are longer than in heterogeneous blocks (Brown, 1981; Kroll & Stewart, 1994). In a variant of this task, blocked cyclic naming, items are named repeatedly. This task has shown similarly robust interference effects, particularly on naming latency (e.g. Belke, Meyer & Damian, 2005; Damian & Als, 2005), but also on the accuracy of naming (Vitkovitch & Humphreys, 1991). There are several advantages to these tasks: naming a small number of items enables careful control over stimulus variables (Damian et al., 2001); related to this, items serve as their own control since they are named in both heterogeneous and homogeneous conditions, and repeated naming minimizes errors (Damian & Als, 2005). However, these features may also be disadvantages, in that both the small number of stimuli and the practice effects that may arise from repeated naming potentially render the task less representative of everyday word retrieval.

An arguably less artificial version of this task is what Oppenheim and colleagues (Oppenheim, Dell, & Schwartz, 2010) called the continuous naming paradigm, in which items are named successively, but not blocked by category. This approach was motivated by findings that semantic blocking was not actually necessary to obtain the semantic interference effect. When semantically related trials were interspersed with unrelated trials, the related items were still named more slowly than unrelated items (e.g. Brown, 1981; Damian & Als, 2005; but see Kroll & Stewart, 1994). Furthermore, Belke, Meyer and

Damian (2005) showed that interference extends to previously un-encountered exemplars of a semantic category, which supported the idea that interference arises from the persistence of spreading activation within a sub-network of semantically related lexical items. The continuous paradigm also has the advantage of not inducing the repetition priming that occurs in cyclic naming, which interacts with semantic interference effects (e.g. Belke et al., 2005; Oppenheim et al., 2010).

In a continuous naming paradigm, Howard, Nickels, Coltheart and Cole-Virtue (2006) investigated the cumulative aspect of semantic interference by asking speakers to name pictures of objects drawn from multiple semantic categories. In their design, items from 24 different semantic categories were interleaved with each other, and with an additional 45 filler items. Between successive members of a given category, there were 2 to 8 intervening items. Naming latencies were shown to increase monotonically with the ordinal position of presentation. That is, latencies increased linearly, at a rate of about 30 msec per successive item from the same semantic category. Howard and colleagues did not compare these results from the semantically related items to the unrelated filler items, which might have served as a baseline for comparison. However, they did adjust RT distributions by subject to account for overall order effects. The lag between semantically related items had no discernable effect on performance.

In a computational simulation, the authors proposed that three properties of the lexicon are necessary and sufficient to produce the cumulative semantic interference effect: shared activation among semantically related items, which spreads top-down from semantic units; priming, a mechanism by which shared activation from a previous presentation persists over time even when other items intervene; and competition, a mechanism by which priming delays subsequent retrieval of a semantically related item. Howard and colleagues implemented priming through incremental increases in the strength of semantic-to-lexical connections, and competition through lateral inhibitory connections among lexical nodes. In a series of subsequent simulations, however, Oppenheim and colleagues (2010) demonstrated that cumulative semantic interference arises as a natural consequence of an error-driven incremental learning mechanism. Error-driven learning, in this scenario, refers to the adjustment of connection weights between semantic features and lexical items after each successive trial based on the discrepancy between the desired activation and the actual activation of a lexical node. In Oppenheim and colleagues' simulation, this involved not only strengthening the semantic-to-lexical connections of target items, but simultaneously *weakening* the semantic-to-lexical connections of items semantically related to target items. This mechanism was able to account for the behavioral findings of Howard and colleagues (2006), as well as other findings in the literature—including, importantly, the generalization of interference to new exemplars of the category (Belke et al., 2005)—without postulating lateral inhibition among lexical items.

Alario and Moscoso del Prado Martin (2010) extended Howard and colleagues' (2006) findings by re-analyzing the Howard et al. data broken down by semantic category. Using a mixed-effects regression modelling approach, they showed that the magnitude of semantic interference varies by category, and that this variability is not accounted for by the overall naming latency for the category. For example, the categories "head gear" and "white goods" (appliances) produced relatively large interference effects but average response times, while the categories of "body parts" and "house parts" both produced smaller interference effects, but with shorter average response times to body parts and longer average response times to house parts. The authors speculated that characteristics of the categories, such as the similarity (or semantic distance) among members, might underlie such variability.

The conclusion from these respective lines of investigation is that, in tasks requiring successive retrieval of multiple categorically related items, the prior presentation or production of a categorically related item impairs subsequent selection of targets from the same semantic category. Whether this occurs directly, through an explicit competitive mechanism at the lexical level (e.g. Howard et al., 2006), or indirectly, through the relative re-weighting of lexical connections (e.g. Oppenheim et al., 2010), is still under debate. Also unresolved is the possible role of extra-lexical contextual effects, such as the evaluation of selected lexical competitors against response criteria (Mahon et al., 2007), selective attention (Roelofs, 2013), biasing mechanisms (Belke & Stielow, 2013; Thompson-Schill & Botvinick, 2006), or the development of ad hoc, task-specific categories (Abdel-Rahman & Melinger, 2009; Barsalou, 1983). Such hypotheses propose that apparent semantic interference effects arise, not through lexical competition, but through the operation of a pre-lexical or post-lexical task-specific process that constrains the pool of response candidates.

Such a top-down process requires some level of awareness of the semantic relatedness of successively presented stimuli in order to generate biases or response criteria. This is certainly a reasonable assumption in blocked naming tasks (Belke & Stielow, 2013). These authors argue that the continuous naming task, by contrast, precludes the generation of top-down biases about the stimuli, or at least precludes the ability to use this information in a predictive fashion. However, awareness of semantic relatedness among the stimuli is also possible, even likely, in continuous naming tasks that involve highly structured stimulus sets, that is, consisting of categories with the same numbers of items spaced at systematic intervals (*cf.* Howard et al., 2006; Belke & Stielow, 2013), and this might influence responses in subtle ways. One advantage of the randomized continuous naming task analyzed here is that the large number of pictures named and the unstructured order of presentation minimize participants' awareness of categorical relationships.

Lexical Retrieval in Aging

Although word-retrieval difficulties are common in aging, the influence of competition from successively presented semantically related items is not well studied in this population. Previous studies have shown that older speakers, particularly over the age of 70, have greater difficulty than do younger people in naming pictures (Au, Joung, Nicholas, Obler, Kaas, & Albert, 1995; Burke & Shafto, 2004; Connor, Spiro, Obler & Albert, 2004; Kavé, Knafo, & Gilboa, 2010; among others), and experience more tip-of-the-tongue states (e.g. Burke, MacKay, Worthley, & Wade, 1991; Dahlgren, 1998), particularly for proper names (Burke et al., 1991; Evrard, 2002; Juncos-Rabadan, Facal, Rodriguez & Pereiro, 2010). The ability to retrieve and produce a word is influenced by a variety of factors, including demographic characteristics of the individual (e.g., age, education) and characteristics of the word itself (e.g., length, frequency).

Lexical factors may also interact with demographic factors. It has been proposed that older adults have particular difficulty with competitive influences during word retrieval (e.g. LaGrone & Spieler, 2006). In their study, name agreement (the number of alternative labels that are used to describe a given picture) affected the picture naming latencies of older adults more than younger adults. In line with this, Vitevitch and Sommers (2003) found that phonological neighborhood density (the number of words phonologically similar to a target word) facilitated word retrieval less for older than younger subjects. That is, younger subjects experienced more ToT states for words from phonologically sparse than dense neighborhoods, regardless of the frequency of the words in the neighborhood, but older subjects showed this density effect only for words from low-frequency neighborhoods. In a recent study, Gordon & Kurczek (2013) showed an interaction effect of neighborhood density and age on picture naming, whereby older adults were slower to name words from

dense than sparse neighborhoods, but younger adults were minimally influenced by density. In the current study, we examine a different source of competition—activation spreading from items presented within the context of the task.

Burke and colleagues (e.g. Burke et al., 1991; Burke & Shafto, 2004) attribute word-retrieval difficulties in aging to the weakening of connections in the lexicon, called the Transmission Deficit Hypothesis, or TDH. According to this theory, phonological encoding of word forms in production is particularly vulnerable to such weakening, because retrieval of phonology relies on the divergent spread of activation from lexical to phoneme representations. (By contrast, the retrieval of semantic information from phonological input during word recognition relies on convergent spread of activation, which provides redundancy to compensate for weakened connections.) The integrity of spreading activation from semantic to lexical units in aging is less clear. Taylor and Burke (2002) propose that, because older adults have more experience with language, their semantic networks will be more highly inter-connected, facilitating the spread of activation. This (largely untested) hypothesis is put forward to explain findings of greater semantic priming during word recognition in older adults (see Laver & Burke, 1993), and led to the further hypothesis that older adults would experience greater semantic interference in picture-word interference tasks. Indeed, in two experiments, Taylor and Burke (2002) found greater differences in response time between semantically related and unrelated distractor words for older than younger subjects.

Semantic interference in older adults has been demonstrated in blocked cyclic naming (Belke & Meyer, 2007; Biegler, Crowther, & Martin, 2008; Schnur, Schwartz, Brecher, & Hodgson, 2006). In the latter two studies, 6 exemplars from each of 12 categories were presented in semantically blocked and mixed conditions over 4 cycles. In both studies, older adult participants showed significantly longer naming latencies to semantically related than mixed blocks after the first cycle (as demonstrated previously for younger subjects). and this interference effect increased over the course of blocks 2 through 4. Biegler and colleagues (2008) also found a significant semantic interference effect when pictures were presented simultaneously in arrays of 6 (either related or mixed), although in this case the interference did not increase across cycles. These studies demonstrate that semantic interference does occur in older adults, but they do not speak to the issue of whether or not semantic interference increases with age.

In the only study to date that directly compared semantic interference in older and younger participants, Belke and Meyer (2007) assessed blocked picture naming performance in several contexts—single object naming; multiple object naming with phonologically related distractors; multiple object naming with semantically related distractors—by measuring naming accuracy and latency, pausing, and eye gaze. Older adults showed longer naming latencies in single object naming, and spoke more slowly in multiple object naming than younger adults. Semantic interference effects did not differ between the two age groups in single object naming, and differed only on some of the measures in multiple object naming (on pause rate and marginally on gaze duration). In multiple object naming, phonological relatedness appeared to facilitate performance in older adults, but to interfere with performance in younger adults, a finding that the authors attributed this finding to the differences in speech rate between the two groups. In sum, what little evidence there is is equivocal with regard to age effects on semantic interference.

Semantic interference has also been investigated in aphasia (Biegler et al., 2008; Hsiao, Schwartz, Schnur & Dell, 2009; McCarthy & Kartsounis, 2002; Schnur, Lee, Coslett, Schwartz, & Thompson-Schill, 2005; Schnur et al., 2006; Schwartz & Hodgson, 2002; Wilshire & McCarthy, 2002). Biegler and colleagues (2008) found semantic interference in

the naming latencies of an individual with fluent aphasia that was of similar magnitude to the control participants, but much greater semantic interference effects in two individuals with non-fluent aphasia. In a much larger group, Schnur and colleagues (2006) also found larger semantic interference effects in individuals with Broca's aphasia, most evident in increased error rates, relative to individuals with non-Broca's aphasia. Two primary mechanisms have been proposed to explain increased difficulty naming items in semantic contexts: 1) "refractory access" (e.g. McCarthy & Kartsounis, 2002), or prolonged inhibition which spreads to semantically related items; 2) difficulty selecting from among co-activated lexical representations (e.g. Wilshire & McCarthy, 2002). Thompson-Schill and colleagues (e.g. Schnur et al., 2005; see also Biegler et al., 2008) have proposed that lexical selection is particularly compromised by lesions in the left inferior frontal gyrus, accounting for the exaggeration of semantic interference in Broca's aphasia. The simulations of Oppenheim and colleagues suggest that the same mechanism that results in semantic interference in healthy participants—error-based learning—can also explain error patterns in aphasia. This issue is still unresolved. In order to correctly interpret findings from individuals with brain damage, particularly older adults, it is necessary to first have an adequate understanding of the premorbid age-related mechanisms underlying word retrieval and word retrieval difficulty.

In the current study we investigate two primary questions. First, does the semantic interference effect observed in structured tasks such as blocked cyclic naming extend to naming tasks with randomly ordered items from widely varying semantic categories? The unstructured nature of our task is arguably more ecologically valid than tasks in which categories with the same number of exemplars are presented at systematically varying intervals. As such, our task minimizes the probability that awareness of the manipulation influences responses. Furthermore, our comparably large dataset allows us to test whether the results of more controlled studies "scale up"; our stimulus set includes 400 pictures from 50 identifiable categories, each named by 142 participants ranging widely in age. The other primary question concerns whether semantic interference is moderated by the age of the participant. If older individuals are particularly vulnerable to lexical competition (LaGrone & Spieler, 2006; Taylor & Burke, 2002), then they should show greater effects of semantic interference than younger individuals. Belke and colleagues (2005) speculated that semantic interference is promoted either by task conditions such as semantic blocking, or in certain individuals with lexical retrieval problems. If that is the case, in an *unblocked* naming task as in the present study, semantic interference may not occur in younger individuals, but may be observed in older individuals. A secondary question involves the potential role that lexical characteristics may play in moderating interference in individual semantic categories. Most existing studies of semantic interference give little consideration to lexical factors. This is of little concern when the same items are compared in homogeneous and heterogeneous conditions, or across repeated cycles, but when the items differ across conditions, as in the continuous naming paradigm (e.g. Howard et al., 2006), lexical differences may moderate the effects between categories.

Methods

This research was approved by the Institutional Review Board of the University of Iowa. Participants were paid \$10/hour for their participation.

Participants

Data are presented from one hundred and forty-two individuals compiled from two previously conducted studies (Gordon & Kurczek, 2013; Gordon, 2012) in which the same naming task was performed. All participants were native English speakers with normal or

corrected to normal vision, and no history, by self-report, of language or learning disability, neurological or psychiatric illness. Participants ranged in age from 22 to 89 years, and approximately 58% were female. Mean demographic data for the participant sample is provided in Table 1, and Figure 1 shows the age distribution of the participants. We also collected information on participants' education level, measured in number of years, and their vocabulary knowledge, as assessed by the WAIS-IV vocabulary scaled score (Wechsler, 2008). However, vocabulary data was only available for the participants ($n = 84$) from only one of the studies.

Stimuli

Four hundred black-and-white line drawings were used as prompts for naming responses. They were collected from several sources: the *Boston Naming Test* (2nd edition, Kaplan, Goodglass, & Weintraub, 2001); the *Object & Action Naming Battery* (Druks & Masterson, 2000), the *Philadelphia Naming Test* (Roach, Schwartz, Martin, Grewal, & Brecher, 1996), and the Snodgrass-and-Vanderwart-like pictures generated by the TarrLab (Rossion & Pourtois, 2004). Pictures were selected to represent a range of common objects with single-word names, from a variety of semantic categories, including both natural and artefactual categories. Target names varied between one to three syllables. Items were categorized according to the semantic category to which they belong. Fifty semantic categories were identified (see Appendix A). In defining categories, we followed Howard et al. (2006) in defining fairly tightly constrained categories. For example, we subdivided the large categories of animals and foods into several sub-categories. Our aim was to maximize the likelihood that relatedness would be widely agreed-upon. Each category contained at least 2 items; no lower limit was set initially on the minimum number of exemplars in a category, under the hypothesis that any two items belonging to a given category might interfere with each other, given sufficient proximity in their presentation.

Procedure

Prior to the main task, there was a familiarization phase in which participants were presented with the pictures on the computer screen, in random order, along with their written intended labels. The purpose of this was to minimize the influence of visual variables such as image complexity, and conceptual variables such as name agreement, and to maximize accuracy (*cf.* Belke & Meyer, 2007; Damian & Als, 2005; Schnur et al., 2006). Thus, participants were not asked to name the picture during familiarization. In the main phase, participants were presented with one picture at a time, presented on a computer screen using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002), and were asked to name it in one word, as quickly and accurately as possible. Items were presented in a different randomized order for each participant, and a different order from the familiarization phase. At the beginning of the experiment, a practice session was conducted to allow participants to adjust to the task, and to calibrate the sensitivity of the voice response box. Thereafter, the experimental items were presented in 16 blocks of 25 items each. In between blocks, participants were offered a break in order to reduce fatigue effects. No participant took breaks of more than a minute or two between blocks.

Each trial consisted of the following steps: a) a fixation point (a cross) appeared at the center of the screen for 2000 ms; b) the picture appeared, along with a beep used to signal the onset of the stimulus; c) the picture remained on the screen until the participant responded or until the trial timed out at 10,000 ms. At the end of the response a red screen appeared for 2000 ms signaling the end of the trial. Response times were calculated from the onset of the picture presentation to the onset of the naming response, triggered by a voice response box. In addition, responses were scored on-line by the experimenter, and audio-recorded for later

transcription using a Shure SM10A headset microphone and a Marantz PMD 680 digital recorder.

Analyses

Only accurate (i.e. target) responses were included in the analysis. Incorrect (non-target) responses accounted for 6.5% of the data. When the voice box was incorrectly tripped, but responses were correct, RTs were manually calculated from the audio-recordings, using Computerized Speech Lab (CSL, KayPENTAX) to measure the latency from the onset of a picture (signalled with a beep) to the onset of the naming response. This accounted for 9.1% of the data¹. Recording malfunctions resulted in the loss of 69 items (0.1%). Outliers were removed, that is, RTs shorter than 400 ms (0.04%) or longer than 3 standard deviations from the mean for each participant (1.7%). In all, 4731 items (8.3% of the data) were excluded from the latency analyses.

We were interested in assessing whether the latency of successive responses in a naming task changes over the course of the task (i.e. order effects); whether order effects depend on the semantic category of the item (i.e. semantic interference effects); and whether these effects change with age throughout adulthood. Thus, our analyses included two participant variables: age in years; education (also in years, by self-report), since it might be expected to moderate the effect of age. An overall order effect was assessed by the trial number of each response (Trial, 1 to 400) under the hypothesis that, given the large number of items, latency of response would slow over the course of the experiment. We also investigated the trial number within each block of items (Trial in Block, 1 to 25), assuming that items within a block were more likely to affect each other, both because they occur in relatively close proximity and because the pause between blocks may serve to (in the words of an anonymous reviewer) “reset” the activation of potential naming responses. Measuring Trial in Block also allowed us to control for experiment-wide order to some extent, because items at a given block position were compiled across all 16 blocks (e.g. Trial in Block position 1 included Trial numbers 1, 26, 51, 76, etc.). While responses were expected to slow somewhat over the course of the experiment, we hypothesized that order effects would speed up over the course of a block, showing short-term practice effects. However, hypotheses of cognitive slowing in aging (e.g. Verhaegen & Cerella, 2008), might predict that the effect of order within a block would differ with age, such that older participants would show reduced practice effects. All participant characteristics and orders of presentation were analyzed as continuous variables.

Semantic Category was coded as a categorical variable with two levels: Related (i.e. belonging to one of the 50 identified semantic categories) or Miscellaneous. On the assumption that response interactions would be most evident within a block, items were only considered to be semantically related if they occurred with at least one other item in the same semantic category within the block. Thus, any items from the identified semantic categories that occurred by themselves within a given block for a given subject were designated as “solo” items and were excluded. (An alternative would have been to consider these as Miscellaneous items; however, on the chance that they might have contributed some interference across blocks, we opted for the more conservative option of excluding them.) This reduced the total number of trials from 56,800 (142 subjects $\times$ 400 items) to 26,762 (an average of 188 per subject). Of these, 22,502 (84%) were from semantically related categories.

¹A comparison of manually and automatically measured RTs for 500 randomly selected items showed a strong correlation ($r = 0.98$). The two measures differed by 37 msec, on average. None of the t-tests comparing a subset of 71 subjects' RT distributions with and without manually calculated responses were significant (see Gordon & Kurczek, 2013).

Response times were log-transformed to reduce skewness in the distribution, and were analyzed with generalized linear mixed-effects modeling, employing the *lmer* function of package *lme4* (Bates, Maechler, & Bolker, 2011) in R 3.0.2 (R Development Core Team, 2013). As noted by Alario and Moscoso del Prado Martin (2010), this approach has the advantage of taking into account individual data points (rather than averaged data), and incorporating random intercepts and/or slopes for items and participants. A series of models was run, beginning with one including only random effects for participants and targets, incrementally adding variables, and comparing successive models to previous ones by means of ANOVAs. Our strategy was to assess the main effects of participant variables, then the main effects of order variables and their interactions with age, then semantic category and its interaction with age and order. Whether or not a variable was retained was determined by conducting an ANOVA comparing each model with the previous one. By means of a chi-squared test, this demonstrated whether or not the newly added variable made a contribution to the model by explaining a significant amount of additional variance in the dependent variable.

Results

Analysis 1: All Semantic Categories

Participant Characteristics—The initial mixed-effects linear regression model assessed the effects of the random variables Participants and Targets (as well as an intercept, which was included in all models). To the random variables, we added the participant variables of Age, Education, and Vocabulary. Adding participant age significantly improved the fit of the Random model ($\chi^2 = 31.51, p < 0.0001$), as did participant education ($\chi^2 = 5.41, p = 0.0201$). Responses were significantly slower the older the participant, and significantly faster the higher the participant's level of education. Adding the Vocabulary measure did not improve the model's fit, probably due, at least in part, by the fact that this information was available for fewer than 60% of our participants. Adding Vocabulary did reduce the effect of Education, however, indicating a high degree of overlap in the variance accounted for by these two variables (this is also indicated by the significant correlation between them [$r = 0.396$] shown in Table 1). Thus, we removed Vocabulary from the model and retained the Education variable.

Order of Presentation—To the model containing participant variables, we added the trial variable, representing experiment-wide order of presentation. It showed a strong slowing effect on reaction time, and significantly improved the fit of the model ($\chi^2 = 47.00, p < 0.0001$). At this point, we replaced our random subject variable, which estimates the intercept for each participant (i.e. his/her "default" RT), with a random Trial by Subject interaction, which estimates both intercepts and slopes (i.e. change in RT by trial) for each participant. This model was a much better fit to the data ($\chi^2 = 66.60, p < 0.0001$), indicating that individuals varied significantly in the degree to which their naming responses slowed over time. This was not, however, accounted for by participants' age, as replacing the trial by subject interaction variable with an interaction of age by trial variable did not significantly improve the fit of the model ($\chi^2 = 0.93, p = 0.3351$). Notably, the main effect of Trial remained significant in the presence of the Trial by Subject interaction, indicating that, despite the individual variance, there was still a general trend of slowing. Next, we added Trial in Block (1–25). This variable also accounted for significant variance, improving the model fit further ($\chi^2 = 29.41, p < 0.0001$). Contrary to our prediction, the effect was in the same direction as the Trial effect, demonstrating overall slowing over the course of a block in addition to slowing over the course of the experiment. This finding does, however, confirm the hypothesis that there are order dynamics within a block of items that extend beyond the general slowing noted over the course of the experiment. As for the

Trial variable, Trial in Block did not interact with age in predicting naming latency ($\chi^2 = 0.32, p = 0.5702$), showing similar effects of order across age.

Semantic Category—In the final stage of model comparisons, we added the categorical variable of Semantic Category (Related vs Miscellaneous). Although the overall difference in latency between semantically related and miscellaneous items was not significant ($\chi^2 = 2.45, p = 0.1176$), the interaction between Semantic Category and Trial in Block was ($\chi^2 = 6.33, p = 0.0119$). This interaction is illustrated in Figure 2, and shows that while naming items from the same semantic category slowed latency across trials within blocks ($r = 0.428$), naming unrelated items speeded latency ($r = -0.231$). Because there were many more semantically related than miscellaneous items, the main effect of Trial in Block found earlier reflects the dominant slowing caused by semantic interference among these items.

We considered how participant age might influence the semantic category differences first by adding an interaction term between Age and Semantic Category—did older adults respond differently to related items compared to unrelated items? The interaction with age significantly improved model fit ($\chi^2 = 15.45, p < 0.0001$). Figure 3 shows that items from the identified semantic categories were named more quickly than items from miscellaneous categories, but this difference increased with age. Put another way, the slowing effect of age was somewhat more pronounced for Miscellaneous items ($r = 0.576$) than for Related items ($r = 0.538$). Our final model comparison was conducted to determine whether the semantic interference effect was moderated by the age of the participants. According to the Transmission Deficit Hypothesis, semantic interference should increase with advancing age due to a more highly interconnected lexicon (Taylor & Burke, 2002). We tested this hypothesis with a 3-way interaction between Trial in Block, Semantic Category, and Age, which did not account for a significant amount of additional variance ($\chi^2 = 0.29, p < 0.8647$). Thus, contrary to our hypothesis, older adults did not appear to experience more semantic interference than younger adults.

Final Model—Parameters for the final model are shown in Table 2. The participant variables of Age and Education both affect response time, age positively ($t = 6.76$, a slowing effect) and education negatively ($t = -2.54$, a speeding effect). Trial order also slows naming latency ($t = 4.40$). Neither the order of Trial in Block ($t = -0.43$) nor Semantic Category ($t = -0.52$) exert significant main effects, but they interact with each other ($t = 2.56$). As shown in Figure 2 above, this interaction arises because the latency of response gets faster for unrelated items, but slower for semantically related items across a block of items. The interaction between Age and Semantic Category ($t = -3.93$) is also significant. As shown in Figure 3 above, this arises because the difference in reaction time between the two sets, although not significant overall, increases significantly with age.

Analysis 2: Selected Semantic Categories

In order to ensure that the results above were robust, we filtered the dataset to include only a subset of the semantic categories. In the full dataset, there were many semantic categories with only a few exemplars. Not only did this increase the potential for item-specific effects to unduly influence reaction times, but it also meant that there were often only 2 items from that category within a block for a given subject (recall that solo items were excluded). These categories could therefore not provide a strong test of interference effects throughout a block of trials. Another advantage of filtering the data was to facilitate comparison of individual semantic categories, since Alario and colleagues (2010) found differences in the degree of interference among different categories. To achieve this, we included only those semantic categories with at least 10 different exemplars in the category, and which occurred at least 4 times in a given block for a minimum of 10 blocks across subjects. This yielded 12 selected

semantic categories (205 different targets), indicated with an asterisk in Appendix A. We also culled the Miscellaneous category in order to eliminate the solo items, just as we did earlier with the semantically related categories. After filtering, the number of remaining trials totaled 16,761 (118 trials per subject on average). Of these, 13,613 (81%) were semantically related.

Model Comparisons—On this filtered dataset, we repeated the analyses as described above, adding participant variables, then order variables, then semantic category and its interactions, and testing to ensure that each variable contributed a significant amount of variance to the model. Although the degrees of variance accounted for differed, the results were essentially the same as the previous analysis. That is, the same variables were found to predict naming latencies. The final model is shown in the right-most columns of Table 2, and illustrates very similar results to the model arrived at in Analysis 1, with one exception: the main effect of Trial in Block remained significant, even in the presence of its interaction with Semantic Category.

Looking at the selected semantic categories individually allowed us to assess the consistency of the semantic interference effect. Correlations between naming latencies and Trial in Block position are shown in Table 3 for each individual category. The correlation for the category of miscellaneous items ($r = -0.343$) demonstrates a gradual decrease in reaction time, consistent with practice effects across the block. By contrast, the correlations for most of the semantically related categories reflect an overall pattern of slowing, consistent with interference. Not all of the related categories follow this trend, however. Notably, reaction time decreases (negative correlations) were found for the categories of Games & Toys, Other Foods, Transportation, and Occupational Tools, although Table 3 shows that these correlations were quite weak, so did not mitigate the interference effect much.

Lexical Characteristics of Categories—In order to explore why some categories exert more interference than others, we examined some of the lexical characteristics of each category. One possible influence that is directly related to semantic interference is the number of items in a category and, by extension, the overall number of trials contributing to the category. A related factor is the number of items at ordinal position number 4, which indicates that 3 previous items from that category occurred with that block for that participant, increasing the opportunity and probably the magnitude of interference (as in Howard et al., 2006). These are highly related measures, of course, but none were particularly good predictors of the magnitude of interference. For example, although the category of Clothing appears to have been slowed (it had the second highest correlation between RT and Trial in Block) by having relatively high numbers of items overall and within blocks, the Bird category showed an even higher correlation, but ranked lower among the semantic categories in terms of all of the above indices.

If differences in the magnitude of interference cannot be explained by co-occurrences within the task, perhaps factors intrinsic to the lexicon might be at play. Lexical frequency is a dominant influence on word retrieval. One possibility is that more frequent items cause greater interference because their resting activation is closer to threshold, and this makes them more viable competitors. An alternative possibility is that lower frequency items are more susceptible to interference from various sources. Here, we see an apparent mean frequency difference between the Related and Miscellaneous sets (with Miscellaneous being higher frequency), although the mean frequencies of individual categories appear to bear little relationship to the magnitude of their respective semantic interference effects.

A more viable hypothesis may be that the degree of semantic interference is influenced by the co-activation of items that arises from spreading activation within the neighborhood of a

target item. Phonological neighborhood density, defined as the number of words related to a target by substituting, omitting or adding one phoneme (Vitevitch & Luce, 2004) has been observed to facilitate lexical retrieval in spoken word production (e.g. Gordon, 2002; Vitevitch, 2002). Here, miscellaneous items are observed to have more neighbors, on average, than related items, which appears to support this hypothesis. On the other hand, because production is semantically driven, words with more semantic neighbors may face increased competition that exacerbates interference from items within the task. As an index of semantic neighborhood density, we used name agreement, as measured by the H-statistic (see Snodgrass and Vanderwart, 1980). On average, the semantically related categories have lower name agreement (higher H-statistics), or more alternative names, than the miscellaneous items, suggesting an additional source of interference for related items. These neighborhood factors might contribute to the variability seen across individual semantic categories but, like the other characteristics discussed above, their relationship to the magnitude of semantic interference is not clear-cut and awaits further study.

Summary & Discussion

Our series of regression analyses illustrated combined influences of participant characteristics, order of presentation, and semantic category on naming latencies. Age exerted a powerful slowing effect on reaction times to name pictures, most notably for items in the miscellaneous category. It is unclear why this might be, as the miscellaneous items were, on average, shorter, higher-frequency words with fewer alternative names (see Table 3). They also had more phonological neighbors on average, which might provide a clue to the age-related decline. Gordon and Kurczek (2013) found that the normally facilitative effect of neighborhood density on word production reverses with age, such that words from dense neighborhoods were retrieved more slowly than words from sparse neighborhoods by older adults. They proposed that the weakening of lexical connections that is hypothesized to occur with age (Burke et al., 1991) reduces the facilitative feedback that neighbors confer on targets, resulting in neighbors becoming more viable competitors. The other participant characteristic, years of education showed a moderate speeding effect, which we presume reflects an increase in vocabulary knowledge. (A limitation of the study was that we did not have vocabulary data on all of our participants.)

Order of presentation also strongly influenced response times, both across the course of the experiment, and within blocks. At both levels, latencies got slower over successive trials, but this turned out to depend on the semantic category. Responses to items from the Miscellaneous category got faster over the course of a block, confirming our original hypothesis that practice effects would occur over the relatively short span of a block. By contrast, responses to semantically related items, which far out-numbered miscellaneous items, got slower throughout the block. This semantic interference effect did not increase with the age of the participants, contrary to expectations. Thus, our results suggest that older adults are not more susceptible to semantic interference as proposed by Taylor and Burke (2002), at least not in the context of a randomized naming task. It remains to be seen whether age differences will be observed in more structured naming tasks designed to promote interference. Furthermore, it may be that our participants, for whom vocabulary and education were not strongly correlated with age (see Table 1), are not representative of the aging population in the sense hypothesized by Taylor and Burke. Future studies should explicitly investigate, not only the relationship between age and vocabulary (which has been studied), but the direct relationship between vocabulary measures and semantic interference in order to test the hypothesis that increases in vocabulary knowledge predict increased semantic effects.

These findings were confirmed in Analysis 2, conducted on a subset of the categories which contained the most items per category and per block. In the spirit of Alario and colleagues' (2010) study, our second analysis also explored the magnitude of the semantic interference effect across selected individual categories. Like those authors, we found a wide range in the amount of interference observed, although there was little correspondence in the findings across the two studies for specific categories (where they happened to overlap). For example, we found robust semantic interference for the category of Body Parts whereas, in the Alario study, this was the only category to show little interference. Such differences are most likely an artifact of the specific items selected and their distribution in the experiment. We attempted to explore other lexical aspects of the categories to further explain the variable amount of interference across categories in our data. Two possible contributing factors relate to spreading activation within the lexicon, to both phonologically and semantically related items. The Related categories had fewer phonological neighbors on average, which might have contributed to reduced facilitation. They also showed lower average name agreement, which might have introduced additional sources of competition.

These hypotheses remain speculative, pending future study. Although it makes sense that different sources of interference—arising both externally (from the task) and internally (from the lexicon)—would contribute to word retrieval, the way in which these effects might combine is difficult to predict. Furthermore, we agree with Alario and colleagues (2010) that aspects of the semantic coherence of a category such as the semantic distance between items (e.g. Mirman et al., 2011) are likely to be critical. However, standardized measures of such dimensions are not widely available or agreed-upon. As noted above, we followed Howard and colleagues (2006) in defining fairly circumscribed semantic categories, but we acknowledge that there is a great deal of subjectivity in defining category boundaries. (The implications of this were well illustrated by Alario and colleagues (2010) in their re-analysis of Howard et al.'s data.)

To conclude, our study contributes to the literature on semantic interference by demonstrating that interference effects can arise in an unstructured and randomized continuous naming task. To the extent that such a task is more ecologically valid, this finding supports the idea that semantic interference effects would generalize to natural word-retrieval contexts. The inclusion of categories which varied widely in the number of exemplars and the randomized order of presentation make it unlikely that participants were able to generate expectancies about the relatedness of the stimuli. Thus, our findings provide further evidence against the notion that interference relies on top-down biasing mechanisms (Belke & Stielow, 2013). In addition, the lack of age differences in semantic interference contributes an important piece of evidence to the investigation of aging effects on access to semantic knowledge.

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Appendix A

Semantic categories, sample exemplars, and numbers of items per category

Category	Sample Items	No.	Category	Sample Items	No.
Artefactual Categories			Natural Categories		
Clothes *	belt, dress, scarf	25	People	baby, girl, woman	4
Jewelry	necklace, ring, watch	3	Occupations *	dentist, jockey, nun	13
Accessories	cane, purse, umbrella	5	Mythical figures	angel, ghost, witch	5
Animal Accessories	muzzle, saddle	2	Body Parts *	arm, bone, finger	18
Other Food *	bread, cheese, popsicle	13	Zoo Animals *	kangaroo, panda, seal	15
Buildings *	barn, church, hospital	12	Forest Animals *	bear, moose, porcupine	13
House Parts	chimney, floor, window	6	Farm Animals	cow, goat, pig	8
Yard	fence, pool, well	5	Birds *	eagle, parrot, turkey	13
Furniture *	desk, mirror, rug	17	Reptiles & Amphibians	frog, snake, turtle	7
Small appliances	clock, iron, radio	5	Underwater Life	crab, octopus, whale	6

Category	Sample Items	No.	Category	Sample Items	No.	
Artefactual Categories			Natural Categories			
Technology	camera, microphone, telescope	4	Bugs	ant, butterfly, spider	7	
Statues	sphinx, statue	2	Other Animals	bat, snail, worm	3	
Transportation *	blimp, canoe, rocket	12	Animal Parts	feather, tail, hoof	3	
Car Parts	tire, wheel	2	Plants	cactus, rose, tree	7	
Road	bridge, road, tunnel	3	Fruits	cherry, lemon, pineapple	8	
House & Garden Tools	broom, hose, rake	9	Vegetables	artichoke, carrot, potato	10	
Workshop Tools	chisel, hammer, screw	9	Nuts	acorn, peanut, walnut	3	
Occupational Tools *	anvil, rope, tripod	11	Geographical Formations	desert, mountain, volcano	3	
Kitchen Implements	fork, spatula, whisk	7	Planets	moon, sun	2	
Tableware	bowl, cup, plate	9				
Office Items	paper, ruler, tape	6				
Containers	barrel, box, can	6				
Mail	envelope, package, stamp	4				
Grooming	brush, comb, razor	3	Total items in semantic categories			370
Smoking	cigar, match, pipe	4	Minimum items per semantic Category			2
Sewing	needle, thimble	2	Maximum items per semantic category			25
Navigation	equator, globe, map	3	Mean items per semantic category			7.4
Lock	key, lock	2				
Weapons	arrow, bomb, guillotine	7	Miscellaneous items			30
Games & Toys *	abacus, ball, swing	13				
Musical Instruments	banjo, harp, saxophone	11	Grand total			400

Note: Categories with asterisks were selected for Analysis 2.

Figure 1.
Distribution of participants across 5-year age groups.

Figure 2.
Interaction between semantically related and miscellaneous items in predicting naming latencies across trials within a block

Figure 3.
Interaction between semantic category and age in predicting naming latencies

Table 1

Mean participant characteristics and inter-correlations.

	Gender	Age (years)	Education (years)	Vocabulary (WAIS-IV ^I)	Reaction Time
% Female	0.577				
Mean		55.9	17.5	13.4	1052.0
St.Dev.		19.7	3.7	2.9	444.3
Min.		22.0	10.0	7.0	401.0
Max.		89.0	38.0	19.0	10427.0
Inter-correlations					
Age			−0.006	0.161	*0.421
Educ.				*0.396	−0.160
Vocab.					−0.151

* Significant at $p < 0.01$, two-tailed ($n = 142$).
^I Vocabulary data was available for only 84 of the participants.

Table 2
Results of Analysis 1 (all semantic categories) and Analysis 2 (selected semantic categories)

Analysis 1			Analysis 2			
Random effects:						
	Variance	Standard Deviation		Variance	Standard Deviation	
Target (Intercepts)	0.00373	0.06103		0.00371	0.06093	
Participant (Intercepts)	0.00459	0.06773		0.00468	0.06841	
Trial × Participant (Slopes)	0.00000	0.00008		0.00000	0.00008	
Residual	0.01078	0.10382		0.01057	0.10280	
Fixed effects:						
	Estimate	Standard Error	t-value	Estimate	Standard Error	t-value
(Intercept)	2.96900	0.03457	85.87 *	2.95200	0.03269	90.30 *
Participant Age	0.00204	0.00030	6.76 *	0.00173	0.00029	5.91 *
Participant Education	-0.00395	0.00155	-2.54 *	-0.00376	0.00155	-2.42 *
Trial	0.00004	0.00001	4.40 *	0.00004	0.00001	4.69 *
Trial in Block	-0.00010	0.00024	-0.43	0.00064	0.00013	5.04 *
Semantic Category	-0.00691	0.01327	-0.52	0.01313	0.01405	0.93
Trial in Block × Semantic Category	-0.00067	0.00026	-2.56 *	-0.00093	0.00029	-3.16 *
Age × Semantic Category	0.00037	0.00009	3.93 *	0.00036	0.00010	3.45 *
	No. Observations = 24517, Targets = 400; Participants = 142			No. Observations = 16761, Targets = 205; Participants = 142		

* Indicates significant contributor to the model

Table 3

Mean lexical characteristics of selected Related and Miscellaneous categories

Category	No. Items	Total Trials	Trials at Ordinal Position ^{1/}	Correlation (LogRT × Trial in Block)	No. Syllables	Log Noun Lexeme Frequency ^{2/}	Neighbourhood Density ^{3/}	Name Agreement (H-Statistic) ^{5/}
Birds	13	1601	22	0.446	1.85	0.52	6.92	0.24
Body Parts	18	2467	40	0.339	1.22	1.55	14.78	0.58
Buildings	12	1603	10	0.372	2.00	1.43	5.75	0.42
Clothing	25	3289	146	0.428	1.46	0.92	13.38	0.54
Other Food	13	1766	23	-0.101	1.77	0.75	8.85	0.30
Forest Animals	13	1590	14	0.341	1.46	0.61	11.54	0.25
Furniture	17	2241	31	-0.101	1.53	1.34	8.06	0.24
Games & Toys	13	1727	12	-0.330	1.62	0.83	10.15	0.61
Occupations	13	1735	16	0.334	1.69	1.10	5.31	0.27
Occupational Tools	11	1455	11	-0.093	1.55	1.15	12.18	0.50
Transportation	12	1528	26	-0.163	1.50	1.32	10.58	0.39
Zoo Animals	15	1888	23	0.358	2.13	0.39	4.60	0.66
Mean Semantic	14.6	1907.5	31.2	0.414	1.648	0.990	9.341	0.417
Miscellaneous Items	30.0	3789	226	-0.343	1.533	1.229	11.067	0.319

^{1/} Ordinal Position4: Number of items occurring as the 4th exemplar of a category in a given block for a given participant

^{2/} Log Noun Lexeme Frequency: Francis-Kucera (1982) frequency of the lexeme form of a noun, log-transformed

^{3/} Neighbourhood Density: Number of words related to a target by the omission, addition, or substitution of a single phoneme

^{4/} Name Agreement: An index of the number of alternative responses given to a picture (see Snodgrass & Vandervort, 1980)