Converging Semantic and Phonological Information in Lexical Retrieval and Selection in Young and Older Adults

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Abstract

The present experiments investigated the influence of combined phonological and semantic information on lexical retrieval, metacognitive retrieval states, and selection in an immediate multiple-choice task. Younger and older adults attempted to retrieve words (e.g., abdicate) from low-frequency word definitions. Retrieval was preceded by primes that were "both" semantically and phonologically related (e.g., abandon), phonologically related (e.g., abdomen), semantically related (e.g., resign), or unrelated (e.g., pink). Younger and older adults benefited from phonological primes in retrieval, and also showed reduced, but reliable, facilitation from "both" primes. Younger and older adults also indicated that they were likely to "know" the answer more often after any related primes compared to unrelated primes. Because there was no facilitation in actual retrieval after semantic primes, this reflects a false "knowing" response. After each retrieval attempt, participants were given the correct answer along with the four primes in a multiple-choice test. Both younger and older adults were likely to false alarm to the "both" and semantic alternatives. When instructed that the prime was not the answer, younger adults decreased their false alarms, but not the older adults. With masked, briefly presented primes, younger adults mimicked the false alarms shown by older adults, suggesting that the high false alarms in older adults reflect an inability to discriminate the source of activation. The present experiments provide strong evidence for age-invariant phonological facilitation, and also suggest that overlapping semantic information moderates the facilitatory effect of phonological information on retrieval, and also produces age-related differences on an immediate multiple-choice task.

Keywords: lexical retrieval; lexical access; tip-of-the-tongue states; semantic memory; aging

Although lexical retrieval seems effortless and automatic in most situations, word retrieval involves complex interactions amongst phonological, semantic and syntactic information to produce meaningful speech (e.g., Dell, 1986). Word retrieval failures can be characterized by the inability to retrieve any one or all of these dimensions, and individuals sometimes report access to partial information about the word in such situations (Brown & McNeill, 1966), as reflected by tip-of-the-tongue (TOT) states. Interestingly, lexical retrieval failures and TOTs increase in older adults (A.S. Brown, 1991; Burke, MacKay, Worthley & Wade,1991; Rastle & Burke, 1996), even though many aspects of lexical processing are relatively uncompromised in healthy older adulthood (Allen, Madden & Crozier, 1991; Cohen-Shikora & Balota, 2016; Whiting et al., 2003).

An important aspect of word retrieval is the nature of information available to constrain lexical retrieval. A prominent spreading-activation account of lexical retrieval suggests that failed activation of phonological units of the word may lead a person to have access to partial information, but prevent them from successfully retrieving the word (Burke, MacKay, Worthley & Wade,1991). Incomplete activation of a lexical item may be a result of impaired access to phonological information about the word, which can be resolved by providing phonological primes or cues (James & Burke, 2000; Meyer & Bock, 1992). Alternatively, some researchers have argued that the availability of phonologically related information in some cases can inhibit/block access to the target word (Jones, 1989; Jones & Langford, 1987). Most research has found evidence for facilitation from phonologically related information (Meyer & Bock, 1992; Perfect & Hanley, 1992; Rastle & Burke, 1996), although some studies have reported inhibitory effects of processing orthographically related information on subsequent target retrieval (Smith & Tindell, 1997; Logan & Balota , 2003). This discrepancy in the literature may be due to differences in stimuli, and specifically, the amount of phonological overlap between cues and targets in these studies (for a discussion, see Logan & Balota, 2003).

A fundamental question that arises from the literature involves the optimal lexical constraints that lead a word to reach threshold for successful retrieval. Priming paradigms that manipulate the information available at the time of retrieval provide insight into the processes underlying lexical retrieval and differentiate between the specific conditions under which such information may facilitate and/or inhibit retrieval. For example, Meyer and Bock (1992) presented participants with low-frequency word definitions, followed by cues, and asked participants to report the answer to the definition and when they could not report the answer, report if they were in a TOT state. The cues in this study were semantically related, phonologically related or unrelated to the target word. They found that cues that were semantically or phonologically related to the target word facilitated target retrieval and phonological cues were more effective than semantic cues, consistent with a spreading-activation account of lexical retrieval (Burke, MacKay, Worthley & Wade,1991). Further, Meyer and Bock (1992) also reported greater TOT occurrence following a semantic cue, than phonological or unrelated cue, suggesting that partial semantic information can produce increases in the subjective experience of a feeling of knowing the correct item, but not having it surpass threshold for retrieval.

A potential limitation of the Meyer and Bock (1992) study is that it only investigated the influence of phonological ***or*** semantic cues and did not examine the influence of combining semantic *and* phonological information on word retrieval. It is likely that when one engages in lexical retrieval, one has partial information about ***both*** phonology and semantics. Indeed, it is the combination of these sources of information that is particularly critical in lexical retrieval, i.e., the semantic context available along with the phonological information attached to that semantic information. Hence, it is particularly important to investigate the influence of primes that contain *both* phonological and semantic information. For example, consider the target word *barter*, which may have a semantic prime, *tariff*, and a phonological prime, *bark*, but also a prime that combines both semantic and phonological

information, *bargain*. Interestingly, such words that are both semantically and phonologically related to a target have been particularly informative in studies of list-learning and false memory (Finley et al., 2017; Watson, Balota & Roediger, 2003; Watson, Balota & Sergent-Marshall, 2001). These studies have shown that false memory for words that are both semantically and phonologically related to list items is greater than the sum of the pure phonological or semantic lists, i.e., superadditivity.

More recently, Oberle and James (2013) and White, Abrams and Frame (2013) have used "both" (semantic-phonological) primes that shared the full first name with the target, to study lexical retrieval of proper names. In the Oberle and James study, participants read descriptions of famous celebrities (e.g., "The actor famous for his role in *Top Gun, Jerry Maguire* and *Mission Impossible*"), followed by the name of the celebrity prime (e.g., Tom Cruise). The primes in this study were either "both" semantically and phonologically related (e.g., Tom Cruise) or unrelated (e.g., Nicholas Cage) to the target photo. After two filler trials, participants viewed the target celebrity photo (e.g., Tom Hanks) and indicated whether they knew, did not know, or were having a TOT for the photo, and also wrote the name if they knew it. Oberle and James (2013) found that "both" primes led to increased correct responses to the target photo, compared to unrelated primes for both age groups. Further, older adults produced more TOTs to the target photo than younger adults overall, but experienced a greater reduction in TOTs than younger adults when primed with "both" primes, compared to unrelated primes. However, Oberle and James (2013) did not compare the influence of such primes on retrieval with primes related *only* in phonology or semantics, and so one could not test for the separate influence of phonology or semantics. Moreover, the "both" primes in this study shared the full first name with the target, and so it is unclear whether the facilitation observed was due to phonological, semantic or lexical overlap.

In the White, Abrams, and Frame (2013) study, participants first viewed target questions (e.g., "What is the name of the 47-year-old blonde female actor who starred in the movies As Good As It Gets, Cast Away…") and either retrieved the target (e.g., Helen Hunt) or indicated whether they did not know the answer or were in a TOT state. After providing an "unknown" or "TOT" response, participants answered a question that embedded the critical prime at the beginning of the question (e.g., the "both" prime would be, "Helen Mirren, the 65-year-old British female actor, won an Academy Award for her leading role in what 2006 movie?"). Primes were phonologically related (e.g., Helen Keller, sharing the full first name with the target), "both" semantically and phonologically related (e.g., Helen Mirren, sharing the full first name *and* occupation with the target) or unrelated (e.g., Martha Stewart, sharing neither phonology nor semantics with the target) to the target name (e.g., Helen Hunt). Importantly, for some targets, primes either shared the full first syllable with the target (e.g., Elvis Presley, a partial "both" prime for Elton John), and for other items, primes shared the first name with the target (e.g., Helen Mirren, a full "both" prime for Helen Hunt). Following exposure to the prime, participants attempted to retrieve the target a second time.

Particularly relevant to the current set of experiments are the results for targets (e.g., Elton John) with first-syllable primes (e.g., Elvis Presley). It is difficult to distinguish between conditions in which the full first name is presented as a prime (e.g., Helen Mirren), from pure phonological or semantic overlap, because lexical overlap could occur in the former case. As noted, this was also a potential concern about the interpretation of the Oberle and James study discussed above. For targets with first syllable primes, the authors reported no differences in TOT resolution between the "both" and unrelated primes, and greater TOT resolution following phonological primes, compared to "both" and unrelated primes. Thus, this study suggests that combined semantic and phonological overlap with the target word in the first syllable does not facilitate TOT resolution, compared to only phonological

overlap. Importantly, however, White, Abrams and Frame (2013) did not compare the influence of "both" primes with only semantic primes, and hence it is difficult to interpret the independent contribution of phonology and semantics from "both" primes. Hence, although both of the previous studies have provided important data regarding the use of "both" primes, there are some differences in the overall pattern of results, likely due to differences in the types of primes (first-name vs. first-syllable) used, the number of retrieval attempts (one vs. two) and the dependent variable (TOT incidence vs. TOT resolution). Also, these studies targeted proper names of famous celebrities, and, as noted, did not include primes that were only related semantically or phonologically to obtain an estimate of the independent contribution of each type of relation. Clearly, further work is needed to clarify the influence of "both" primes, compared to the independent contribution of phonological or semantic primes.

The present experiments were designed to investigate healthy younger and older adults' ability to retrieve words from low-frequency word definitions in a priming context including "both" (combined semantic-phonological), phonological, semantic and unrelated primes. We also included metacognitive judgments in order to assess the participants' retrieval state (e.g., whether they thought they knew the answer or were in a TOT state) immediately after the definition. Finally, we also examined the ability to immediately select the correct answer amongst alternatives as a function of prime type. In this way, we were able to examine the lingering effects of prime information in an immediate multiple-choice task, particularly on trials in which participants did not retrieve the correct answer. It is possible that the prime information may have differential influences on explicit lexical retrieval, compared to selecting the correct answer in a multiple-choice task, since the latter task may produce a source discrimination problem due to the brief presentation of both the prime (on related trials) and the definition for the target.

As noted earlier, we were particularly interested in the effects of aging, because word-finding failures are the most common cognitive complaint among older adults (Ossher et al., 2013; Sunderland et al., 1986). Consistent with the spreading-activation account/transmission-deficit hypothesis developed by Burke and colleagues (1991), these word-retrieval difficulties could be a result of insufficient or impaired activation of phonological information, in that older adults have weaker connections between the phonological and lexical nodes of a word, leading to a loss of activation transmitted across these connections. Alternatively, greater word-retrieval difficulties in older adults may be related to other age-related cognitive changes, such as a lack of flexibility in constraining memory retrieval (Jacoby et al., 2005) and/or an inability to inhibit irrelevant information (Balota, Dolan, & Duchek, 2000; Hasher, Zacks, & May, 1999). This is also consistent with the blocking/inhibition deficit hypothesis that suggests that persistent alternates prevent target retrieval (Anderson & Bjork, 1994; Brown, 1991; Jones, 1989; Reason & Lucas, 1984; Schacter, 1999). Although the transmission-deficit account of age-related differences in lexical retrieval has been more consistently supported in the aging literature, it is possible that the more natural confluence of both semantic and phonological information in lexical retrieval may produce some evidence of inhibition that may be exaggerated in older adults.

The present study was designed to address three issues regarding age-related changes in lexical processing. First, we were interested in examining the influence of competing lexical information on both metacognitive judgements and word retrieval through a priming paradigm in younger and older adults. As shown in Figure 1, on each trial, participants read low-frequency word definitions and descriptions and attempted to retrieve a word that fit the definition. Retrieval was preceded by a prime that was phonologically, semantically, “both” phonologically and semantically related, or unrelated to the target word. Consistent with the transmission deficit account, we predicted that phonological

primes would facilitate word retrieval, compared to unrelated primes, as found in previous studies (Burke, MacKay, Worthley & Wade, 1991; James & Burke, 2000; Meyer & Bock, 1992; White & Abrams, 2002), and semantically related primes would reduce the likelihood of retrieving the target word, at least compared to phonological primes. This prediction is based on the transmission-deficit assumption that lexical retrieval failures often involve insufficient activation from the lexical node to the phonological nodes, via a spreading activation mechanism. Semantic primes do not provide this important phonological activation (White, Abrams & Frame, 2013). On the other hand, the inhibition deficit/blocking hypothesis would predict specific inhibition from semantically related primes, because they would serve as persistent alternates and interfere with target retrieval. The performance on the "both" prime would be an important test of competing hypotheses, due to shared phonology and semantics with the target word. Facilitation from "both" primes would support the transmission deficit account, according to which insufficient activation of phonological units causes lexical retrieval failures, and thus providing phonological and semantic primes/cues (as in the "both" prime) should bridge this lexical gap. However, it is also possible that the activation of the "both" prime may supersede an interactive threshold which may direct attention to that item, in which case it may prevent activation of the target word, at least until the prime activation eventually dissipates. If this activation persists, the "both" prime may in fact produce inhibition. Inhibition from "both" primes would provide support for the inhibition deficit account, and suggest that "both" primes present a unique opportunity for blocking to occur because of the increased activation of a likely alternative that affords convergence of semantic and phonological information.

There is clear precedent that "both" primes may provide a unique influence on performance. For example, as noted earlier, Watson, Balota and Roediger (2003) had participants study word lists that converged on a critical non-presented item semantically, phonologically or in a hybrid list of both.

They found that false recall of the non-presented item was highest in the hybrid list, which produced superadditive effects, i.e., greater than the summed influence of semantic and phonological information (see also, Finley et al., 2017). Watson et al. argued that this pattern may be due to the fact that semantics and phonology are typically uncorrelated, so when both of these codes are activated, it is a rare and atypical event that directs attention to the critical item. Hence, in the present set of experiments, exposure to the "both" prime in the context of a low-frequency word definition may direct attention to its lexical representation, and potentially block or inhibit subsequent target retrieval. In contrast, it is possible that the both primes may produce passive activation, without directing attention, and hence, merely produce facilitation due to the phonological overlap with the target, as predicted by the transmission-deficit hypothesis (see Finley et al., 2017 for such an alternative activation-based account). Importantly, as noted, there is currently no conclusive evidence regarding the potential superadditive, additive, or underadditive influence of the overlap of semantic and phonological information in the lexical retrieval domain, even though different theoretical perspectives described above, could predict each of these patterns.

Second, we were interested in studying the metacognitive states experienced during lexical retrieval across the different prime types and between age groups. As shown in Figure 1, before producing their overt response to the definition, participants specified their retrieval state by choosing "1" if they knew the answer, "2" if they did not know the answer, "3" if they had a word in mind which they did not think was correct, and "4" if they were in a TOT state. Different types of primes may modulate the metacognitive states for the target word, which would provide further insights into the mechanism(s) underlying the retrieval process. We specifically included the "another incorrect word in mind" option to be able to distinguish between the inhibition and transmission-deficit hypothesis. If blocking underlies retrieval failure, as suggested by the inhibition-deficit account,

participants should be more likely to choose this option over TOT states when they are unable to retrieve the answer, and this pattern may vary across the different prime types and age groups. Note that it is possible to be in a TOT state, and also have an alternate word in mind (Burke et al., 1991), and so these options were not mutually exclusive. However, our instructions clearly specified that participants should choose the "another incorrect word in mind" option in any situation where it applies, regardless of whether they were in a TOT state or not. Thus, even though the number of TOTs may be underestimated through this procedure and may be affected by age-related differences, we should be able to examine if another word is coming to mind that may serve as a potential blocker in lexical retrieval. Hence, the inhibition account predicts that there will be an inhibitory influence of related primes on the response option of an alternative word coming to mind, whereas, if passive activation via the transmission deficit hypothesis is involved, then one may not expect an influence of prime type on alternative words coming to mind. Examining these retrieval states within the present priming context will help us distinguish between the two theoretical perspectives.

Turning to the influence of aging, we would expect older adults to report more TOTs compared to younger adults (Burke, MacKay, Worthley & Wade,1991; Heine, Ober & Shenaut, 1999; Maylor, 1990). However, this may vary as a function of prime type because, as noted above, Oberle and James (2013) found that older adults produced a greater reduction in TOTs following exposure to "both" primes, compared to younger adults. Further, the inhibition deficit account predicts that older adults are more sensitive to persistent alternates (Hasher, Zacks & May, 1990), and thus should report greater "other incorrect word in mind" states, compared to young adults.

The third and final goal of this project was to examine the consequences of prime information in selection of possible answers to a target question on an immediately following multiple-choice test (see Figure 1). There is evidence that older adults may have some difficulty excluding prime

information to select the correct answer from a set of alternatives. For example, Logan and Balota (2003) showed that, compared to younger adults, older adults were specifically impaired at avoiding the interfering prime information in a word fragment completion task when word fragments were preceded by suprathreshold blocking primes. Specifically, older adults had difficulty completing a fragment (e.g., A_ L_ _GY) with an earlier studied item (e.g., ALLERGY) if the fragment was immediately preceded by an orthographically similar word (e.g., ANALOGY). Instead of producing the target word (e.g., ALLERGY), they were likely to produce the blocking prime (e.g., ANALOGY). They also found that if blocking primes were presented near threshold priming conditions to younger adults, intrusion rates among younger adults increased, and they performed similar to older adults in the extended prime duration. Logan and Balota (2003) argued that the increased intrusion rate for the threshold primes in the younger adults likely resulted from younger adults not being able to attribute the source of the activation of the incorrect response, which led to the production of that item. Therefore, in the current paradigm, following the attempted word retrieval from a definition, participants were presented with the target word, along with the four primes in a multiple-choice test. In this way, we were able to simultaneously test the influence of the prime on lexical retrieval success, and also the influence of the persisting prime information on an immediate multiple-choice task. If older adults have difficulty discriminating the source of activation (i.e., from the prime or from the low-frequency word definition), we expect to find an increased likelihood of selecting a semantically related prime, as opposed to the correct answer, on the immediate multiple-choice test. Specifically, because this task is driven by low-frequency word definitions that direct attention to semantics, we may expect older adults to be more prone to choose the previously presented semantic and “both” primes on the multiple-choice task.

As an overview of the experiments, in Experiment 1, we examined the effect of prime information on lexical retrieval in healthy younger and older adults with a relatively brief (300 ms) presentation of the prime immediately after the definition was read. Participants were not told about the relevance of the prime information in the experiment. In Experiment 2, we explicitly informed younger and older adults that the 300-ms prime was not the answer to the definition, and investigated the participants' ability to respond to instructions and inhibit distracting prime information to retrieve the target. In Experiment 3, we tested healthy young adults under threshold priming conditions (48 ms) to investigate the influence of automatic lexical activation of competitors on lexical retrieval. Following Logan and Balota (2003), we were interested in examining whether younger adults would be more influenced by the prime in the multiple-choice test, when there was no clear conscious availability of the prime information due to its short duration and masked presentation.

Experiment 1

Method

Participants. Thirty-six young adults (M_{age} = 20.3 years, *SD* = 2.2) were recruited from undergraduate courses at Washington University and received course credit for participation. Thirty-six older adults (M_{age} = 69.8 years, *SD*=5.2) were recruited from the Washington University Aging and Development Subject Pool and received monetary compensation for participating. Mean score on the Shipley Vocabulary Test for younger adults was 33.92 (*SD* = 3.20), and mean score for 12 older adults in the sample was 35.3 (*SD* = 1.78). Vocabulary scores for 24 older adults were lost due to a system error, but based on the available data, older adults had marginally higher vocabulary scores than younger adults, $t(34.9) = 1.91$, $p = .063$. Younger adults had fewer years of education 13.83 (*SD* = 2.8), compared to the older adults, 16.24 (*SD* = 2.7), $t(67.9) = 3.62$, $p < .001$. All participants were

native English speakers. The study was approved by the Institutional Review Board at Washington University in St Louis.

Materials. The stimuli consisted of 100 target words, and each target word was matched with four other words which served as "both", phonological, semantic, or unrelated primes. Each target word also had a definition ranging from 3-22 words. Forty of the target words were proper nouns (names of people or places) and the remaining sixty were common nouns, adjectives, and verbs. Proper names were chosen from the following four categories: literature (22.5%), entertainment (20%), politics (15%) and geography (42.5%) and ranged from names of persons, countries and movie titles. Thirty-eight target words and definitions were taken from previous studies, and an additional five were adapted (i.e., their related words became targets in the present study) (Burke et al., 1991; James & Burke, 2000; Meyer & Bock, 1992). The remaining target words, primes and definitions were specifically developed for this experiment. The Appendix lists the full set of stimuli.

As shown in the Appendix, there was considerable variability across items in the degree of semantic and phonological overlap across the prime conditions with the target. Most often, the "both" and phonological primes overlapped in the first letter, but sometimes also in the overall syllabic structure and the first onset cluster and vowel. Of course, it is particularly difficult to select a "both" prime that is equally semantically and phonologically related to the target, as the pure semantic and phonological primes, respectively. Hence, in order to quantify the degree of phonological and semantic relationship, which will be used as covariates in subsequent analyses, we took two approaches.

First, we conducted a pilot study on Amazon Mechanical Turk. Specifically, it is important to evaluate if the stimuli in the "both" condition are similar to the phonological condition in phonology, and similar to the semantic condition in semantics. On each trial, participants were presented the target word and one of the three related primes (i.e., "both", phonological or semantic). Forty participants

(M_{age} = 36.1 years, *SD* = 8.9), rated the 300 target-prime word pairs on a 7-point Likert scale with ratings that ranged from 1 (*not related at all*) to 7 (*highly related*) for relatedness in sound **or** meaning. The type of rating task was manipulated between-subjects, with 19 participants randomly assigned to the phonology/sound condition, and 21 participants randomly assigned to the semantic/meaning condition. As shown in Figure 2, the primes nicely achieved the goal. Specifically, the "both" primes were very similar to the phonological primes when rated on sound (mean rating for "both" primes = 4.29, mean rating for phonological primes = 4.62), whereas the "both" primes were very similar to the semantic primes when rated on meaning (mean rating for "both" primes = 4.34, mean rating for semantic primes = 4.69). Having said this, the relatively small differences in the "both" primes from the semantic and phonological conditions in the meaning-based rating and sound-based rating were both reliable ($p < .05$), and therefore we used these ratings as covariates in subsequent analyses reported in the paper to account for these small differences between the primes. Overall, however, the ratings displayed in Figure 3 indicate that the stimuli conform to the constraint of having relatively similar ratings in the "both" condition to the pure phonological and semantic conditions.

Second, we measured the orthographic distance between the primes and targets via the Levenshtein distance measure, which calculates the number of insertions, deletions or substitutions required to transform one letter string to another and hence is a measure of orthographic similarity between prime and target. Figure 3 displays the mean Levenshtein distances between primes and targets across the four prime conditions. The "both" primes had similar Levenshtein distances (*M* = 5.09) to phonological primes (*M*=4.40), although there was a reliable difference between them (p = .001). The distances for the semantic primes (*M*=7.08) did not differ from the unrelated primes (*M* = 6.95), p = .417. Given that there were reliable differences in phonological overlap between the "both"

and phonological primes, we also used these Levenshtein distance estimates as covariates in subsequent analyses.

Procedure. Each participant received all 100 target words, presented in a random order, in four blocks of 25 trials. For each participant, each prime type (both, phonological, semantic and unrelated) occurred for 25 words, and prime type for each target word were counterbalanced across participants, such that every participant received one of the four prime types for each target, and neither primes nor targets were repeated within a given participant.

Each experimental trial consisted of five components: definition, prime, state declaration, response, and multiple-choice (see Figure 1). Each definition was presented one word at a time, with each word of the definition presented for 500 ms at the center of the screen. After the last word of the definition, a 750 ms delay was presented and then the prime was presented 300 ms and was immediately followed by a query asking participants to indicate the retrieval state they were in. As shown in Figure 1, participants were instructed to press "1" if they knew the answer, "2" if they did not know the answer, "3" if they had a word in mind which they did not think was correct, or "4" if they were in a tip-of-the-tongue state. Based on Brown and McNeill (1966), in the instructions before the experimental trials, participants were told that a TOT state was a situation in which they know the answer but cannot come up with it right away, though they feel it is on the verge of coming to them. We also instructed participants to choose the "other word in mind" option in any situation where it applied, regardless of whether it was a TOT state or not. After they made their metacognitive decision (or 15 seconds had passed) participants were asked to type in any word they had in mind or press a "0" if no word came to mind. If participants did not type anything within 12 seconds, the next screen was presented which included the multiple-choice question. Here, participants were prompted to choose the correct answer for the definition and were provided with five options: the correct answer, and the four

different prime types ("both", phonological, semantic, or unrelated), with one of the primes being the stimulus presented on that trial for that participant. The options were presented in a random order. After selecting an option, participants saw a blank screen for 750 ms before seeing the first word of the next definition. After every 25 trials, participants received a short break and continued with the experiment when they were ready.

Results

We conducted all analyses using repeated-measures Analysis of Variance (ANOVA) on participants (F_1) and items(F_2). In initial analyses, we also examined the effect of word type (proper names vs. non-names) on retrieval states, target retrieval accuracy and performance on the multiple-choice task. While proper names produced greater target retrieval accuracy than non-names overall, in Experiment 1, $F_1(1, 71) = 107.97$, $p < .001$, $\eta_p^2 = .60$, Experiment 2, $F_1(1, 63) = 65.79$, $p < .001$, $\eta_p^2 = .48$, and Experiment 3, $F_1(1, 35) = 35.28$, $p < .001$, $\eta_p^2 = .50$, word type did not interact with any higher-order terms in any other analyses, across the three experiments. Hence, all reported analyses have been collapsed across word type.

Retrieval State Declaration. There were four retrieval states that participants could respond with on a given trial: 1) They know the correct answer to the definition; 2) They don't know the correct answer to the definition; 3) They have another incorrect word in mind; 4) They are in a TOT state[1]. Figure 4 (Panel 1) displays the mean percentage of retrieval states within each prime type, as a function of age. In order to analyze these results, we conducted a 4 (Prime-Type) x 2 (Age Group) ANOVA on each of the four declared states by the participants.

First, consider the "know the correct answer" response, the ANOVAs revealed a main effect of prime condition, $F_1(3,210) = 13.36$, $p < .001$, $\eta_p^2 = .16$; $F_2(3, 297) = 24.06$, $p < .001$, $\eta_p^2 = .19$, no effect of age group by-participants ($F_1 = 1.64$), which was reliable by items, $F_2(1,99) = 10.96$, $p = .001$, $\eta_p^2 =$

.10, and no interaction ($F_1 < 1$; $F_2 < 1$). These results indicated that there was a greater percentage of "know" responses in the "both" ($p < .001$), phonological ($p < .001$), and semantic ($p < .001$) conditions, compared to the unrelated condition, indicating that participants were sensitive to any relation with the prime in making their "know" responses. Item analyses also revealed that older adults reported a greater percentage of "know" responses than younger adults ($p = .001$).

Turning to "don't know" responses, the ANOVAs yielded a main effect of prime condition, $F_1(3,210) = 9.28$, $p < .001$, $\eta_p^2 = .18$; $F_2(3, 297) = 11.22$, $p < .001$, $\eta_p^2 = .10$, a main effect of age group $F_1(1,70) = 9.42$, $p = .003$, $\eta_p^2 = .12$; $F_2(1,99) = 48.26$, $p < .001$, $\eta_p^2 = .33$, and no interaction ($F_1 < 1$; $F_2 < 1$). This result indicated a higher percentage of "don't know" responses in the unrelated condition, compared to the "both" ($p = .005$), phonological ($p < .001$), and semantic ($p < .001$) conditions, and also a greater percentage of "don't know" responses reported by older adults compared to younger adults ($p < .001$). Hence, these results mirrored the "know" responses.

Next consider the "other word in mind" responses. The ANOVAs revealed a main effect of age group, $F_1(1,70) = 51.85$, $p < .001$, $\eta_p^2 = .43$; $F_2(1,99) = 194.4$, $p < .001$, $\eta_p^2 = .66$, a main effect of prime condition $F_1(3,210) = 2.81$, $p = .041$, $\eta_p^2 = .04$; $F_2(3, 297) = 4.29$, $p = .005$, $\eta_p^2 = .04$, and no interaction ($F_1 = 1.4$; $F_2 < 1$). This result mainly indicated greater percentage of "other" responses reported by younger adults, compared to older adults ($p < .001$). If "other responses" could be construed as blocking with another word in mind, then it appears that if anything, younger adults are more likely to exhibit this type of blocking.

Finally, for TOT responses, the ANOVAs yielded no effect of age group by-participants, ($F_1 = 1.09$), which was reliable by items, $F_2(1,99) = 6.07$, $p = .015$, $\eta_p^2 = .06$, a main effect of prime condition, $F_1(3,210) = 3.61$, $p = .014$, $\eta_p^2 = .05$; $F_2(3, 297) = 3.91$, $p = .009$, $\eta_p^2 = .04$, and no interaction between age group and prime type ($F_1 = 2.04$, $F_2 = 2.53$). These results indicate that there is

a greater percentage of TOT responses following unrelated primes, compared to "both" (p = .023) and phonological primes (p < .001). It is also noteworthy that younger adults produced *more* TOT states compared to older adults, at least in the item analyses. To adjust for any differences in the opportunity for TOTs, we also calculated TOTs as a proportion of unsuccessful retrievals (e.g., incorrect "know", incorrect TOT, correct TOT, incorrect "other" and "don't know" responses). As described in James and Burke (2000), correct TOTs were defined as trials on which a participant responded TOT and selected the correct target word on the multiple-choice test. Incorrect TOTs were defined as trials on which a participant responded TOT but did not select the target word on the multiple-choice test. Incorrect "know" responses were trials on which a participant responded "know" and typed an incorrect answer. Finally, we also included an incorrect "other" option, for trials on which a participant responded, "other incorrect word in mind" and typed in an incorrect answer. These analyses revealed no effect of age group (F_1< 1; F_2 <1), or prime condition (F_1<1; F_2 <1), and no reliable interaction (F_1= 1.72; F_2 <1).

Target Retrieval Accuracy. Figure 5 (Panel 1) displays the mean accuracy for target retrieval for each prime condition, for younger and older adults. A 2 (Age Group: Young, Old) x 4 (Prime Condition: "Both", Phonological, Semantic, Unrelated) ANOVA yielded a main effect of prime condition, $F_1(3, 210) = 21.76$, $p < .001$, $\eta_p^2 = .23$; $F_2(3, 297) = 44.66$, $p < .001$, $\eta_p^2 = .31$, no main effect of age (F_1<1; F_2<1), and no evidence of a reliable interaction (F_1<1; F_2<1). Overall, planned comparisons revealed that phonological primes produced higher target accuracy than semantic primes, $t(71) = 7.05$, $p < .001$, "both" primes, $t(71) = 4.06$, p <.001, and unrelated primes, $t(71) = 7.34$, p < .001. Interestingly, "both" primes produced higher target accuracy than semantic primes, $t(71) = 2.88$, $p = 0.005$, and unrelated primes, $t(71) = 2.23$, $p = 0.029$, suggesting some phonological facilitation even from the "both" primes. Target accuracy for semantic primes did not differ from unrelated

primes, $t(71) = 0.43$, $p = .67$ (see Sections 1, 2 and 3.1 in Supplementary Materials for analyses controlling for syntactic class, number of syllables and age-related differences in retrieval of proper names vs. non-names for this experiment and the subsequent experiments).

To account for any differences in the strength of the phonological/orthographic relations between phonological and "both" primes (see Materials section), we examined the effect of the two prime conditions on target retrieval accuracy at the item level, after accounting for the phonological rating for the prime-target pair as well as the Levenshtein distances between the prime-target pairs. After standardizing the phonological ratings and Levenshtein distance measures (to account for item-level variability), we computed a mean composite score for each prime-target pair, such that higher composite scores reflected greater phonological ratings and higher orthographic overlap with the target. Then, we included this mean composite score as a covariate in our analyses for each experiment. A one-way analysis of covariance (ANCOVA) revealed a main effect of prime condition, after controlling for the composite in Experiment 1, $F_2(1,97) = 23.96$, $p < .001$, and also a main effect of the composite, $F_2(1,97) = 14.89$, $p < .001$. These results suggest that although higher composite scores do predict retrieval accuracy, the difference in facilitation between the phonological and "both" primes persists, even after controlling for differences in ratings and orthographic overlap. Thus, it appears that the presence of the additional semantic relationship in the both primes reduces the influence of phonological facilitation.

Multiple-choice. Table 1 displays the mean accuracy in multiple-choice questions, as well as the proportion of incorrect selections chosen for each prime condition. First, consider overall accuracy in the left most column. A 2 (Age Group: Young, Old) x 4 (Prime Condition: "Both", Phonological, Semantic, Unrelated) ANOVA revealed no main effect of age ($F_1<1$; $F_2=2.41$), no evidence of an interaction ($F_1<1$; $F_2<1$), and a main effect of prime condition, $F_1(3, 210) = 16.9$, $p < .001$, $\eta_p^2 = .19$;

$F_2(3, 297) = 18.55$, $p < .001$, $\eta_p^2 = .16$. Follow-up comparisons revealed that phonological primes yielded higher accuracy in the multiple-choice than semantic, $t(71) = 5.84$, $p < .001$, and "both" primes, $t(71) = 4.16$, $p < .001$. Multiple-choice accuracy in the semantic prime condition was reliably lower than the unrelated prime condition, $t(71) = 4.85$, $p < .001$. There were no differences in multiple-choice accuracy amongst the other prime conditions. A potential concern with these results may be that since some of the primes for the proper-name targets were non-names, it may inflate accuracy in the task specifically for proper name targets, since participants can easily rule out the non-name alternatives. We addressed this concern by excluding proper-name targets for all three experiments in Section 3.2 in Supplementary Materials, and the overall pattern of results remains unchanged.

We also analyzed the errors participants made in the multiple-choice task, as shown in columns 2 to 5 in Table 1. A 2 (Age Group: Young, Old) x 4 (Prime Given: "Both", Phonological, Semantic, Unrelated) x 4 (Prime Chosen: "Both", Phonological, Semantic, Unrelated) ANOVA yielded a main effect of the prime chosen, $F_1(3, 210) = 543.31$, $p < .001$, $\eta_p^2 = .88$; $F_2(3, 297) = 117.6$, $p < .001$, $\eta_p^2 = .54$, no main effect of age group by participants, ($F_1 < 1$) but a main effect of age group by items, $F_2(1, 99) = 7.38$, $p = .008$, $\eta_p^2 = .07$. We also observed no effect of prime given by participants ($F < 1$), but a main effect of prime type by items, $F_2(3, 297) = 4.15$, $p = .007$, $\eta_p^2 = .04$. The main effect of the chosen prime was qualified by a reliable interaction between the chosen prime and the prime given, $F_1(9, 630) = 8.7$, $p < .001$, $\eta_p^2 = .11$; $F_2(9, 891) = 20.24$, $p < .001$, $\eta_p^2 = .17$. As shown in Table 1 (by looking at the diagonals), this interaction primarily reflects the fact that when participants did not choose the correct answer, they were more likely to choose the prime given than the other primes, which was greatest in the semantic and "both" conditions. The overall three-way interaction among age group, prime given and prime chosen was not significant by participants, $F_1(9, 630) = 1.27$, $p = .248$, but was significant by items, $F_2(9,891) = 2.65$, $p = .005$, $\eta_p^2 = .03$. This latter pattern primarily reflects older adults

choosing the semantic alternative on the multiple-choices test more often when presented with the semantic prime than younger adults (10%), whereas, the younger adults choosing the "both" alternative more often when presented with the "both" prime than the older adults (6%). Analyses excluding proper-name targets to address potential inflation of errors were overall consistent with the results reported here, and are reported in Section 3.2 in Supplementary Materials.

Discussion

Results from Experiment 1 support the hypothesis that lexical retrieval is facilitated when younger and older adults are presented with phonological primes. Phonological primes produced the highest accuracy in target retrieval for both younger and older adults, compared with "both", semantic and unrelated primes. Further, "both" primes also showed some reduced, but reliable facilitation compared to semantic and unrelated primes. Importantly, this pattern persisted after accounting for differences in the phonological ratings and orthographic overlap between the phonological and "both" primes, suggesting that the reduced facilitation from "both" primes is likely a result of semantic overlap with the target. We return to this issue again in the General Discussion.

Overall, these findings are consistent with the transmission-deficit hypothesis, according to which lexical retrieval failure is a result of weaker connections between concepts and their phonology, and factors that strengthen these connections (i.e., phonological primes) are age-invariant, implying that both younger and older adults benefit similarly from them (MacKay & Burke, 1990). Previous studies on tip-of-the-tongue states have also shown that phonological priming benefits lexical retrieval in both younger and older adults (James & Burke, 2000; Rastle & Burke, 1996). Interestingly, we did not observe a reduction in TOT states with phonological primes, which we will also address in the next experiment.

The state declaration data led to two patterns of results that are particularly intriguing. Specifically, we found that participants were more likely to report that they "know the answer" following "both", phonological, and semantic primes, compared to an unrelated condition. The higher percentage of "know" responses in the semantic condition, compared to the unrelated condition, is particularly intriguing since there was no difference between the semantic and unrelated conditions in correct retrievals. The increase in the "know" responses in the phonological and "both" conditions could have been phonologically mediated, and indeed these conditions did yield higher retrieval accuracy. Hence, it appears the presence of any related prime led to a false feeling of knowing, which was age invariant. The second intriguing aspect of the state declaration results was that older adults overall produced fewer "other" responses compared to younger adults. This is opposite to what one might expect from an age-related inhibitory deficit. Moreover, there was some evidence that older adults produced fewer TOTs in Experiment 1, compared to younger adults. We discuss this pattern further in the General Discussion section, after an attempted replication in Experiment 2.

Both younger and older adults performed similarly in the multiple-choice task, and semantic primes produced the lowest accuracy, indicating some potential interference from related information in the multiple-choice task. This effect was also reflected in the errors participants made in the multiple-choice task, in that both younger and older adults were more likely to choose semantically related and "both" primes as potential correct answers, compared with phonological and unrelated primes. Surprisingly, we did not observe a disproportionate age-related difference in multiple-choice errors in the participant analyses, in that older adults were not any more likely to choose the given prime than younger adults, even though there was a marginal trend in the expected direction in the semantic prime condition, such that older adults incorrectly chose semantic primes in the multiple-choice more often than younger adults, $t(68.1) = 1.68$, $p = .096$, and the three-way interaction was

significant in the item analyses. It is important to note that these results are inconsistent with the findings of Logan and Balota (2003), where older adults showed a reliable, disproportionate increase in intrusion rates when they were presented with a blocking prime.

One possible explanation for the results from the multiple-choice task is that some participants may have assumed that the prime that they saw was in fact the correct answer to the definition, because participants were not instructed about the relevance of the prime to the target retrieval task. In Experiment 2, we explicitly informed participants that the prime was *never* the answer to the definition and investigated whether younger and older adults are able to control the activation of the prime word and correctly retrieve the target word. Based on the results from Logan and Balota (2003), we predicted that younger adults would respond to the instructions and would be less likely to choose the prime they saw as the answer in the multiple-choice, whereas older adults would be specifically impaired at controlling the prime activation and continue to choose it as the answer in the multiple-choice. Regarding correct target retrieval, we would continue to expect phonological facilitation in this study if the influence of the primes is indeed automatic, and hence not under control of the participants.

Experiment 2

Method

Participants. Thirty-two younger adults (M_{age} = 19.7 years, *SD* = 1.6) were recruited from undergraduate courses at Washington University and received course credit for participation. Thirty-three older adults (M_{age} = 71.6 years, *SD* = 8.7) were recruited from the Washington University Aging and Development Subject Pool and received monetary compensation for participating. Mean score on the Shipley Vocabulary Test for younger adults was 33.96 (*SD* =3.03), and mean score for older adults was 34.27 (*SD* =3.66). Vocabulary scores for younger and older adults did not differ, $t(61.5) = 0.36$, *p*

= .71. Mean years of education for younger adults was 13.34 (*SD* = 3.92); mean years of education for older adults was 15.31 (*SD* = 2.71), which produced a reliable difference, $t(54.9) = 2.354$, $p = .022$. All participants were native English speakers. Data from one older adult was lost due to a system error, so the final sample consisted of 32 older adults. The study was approved by the Institutional Review Board at Washington University in St Louis.

Materials and Procedure. Materials and procedure were identical to those in Experiment 1, with one exception. Before participants began the experiment, they were specifically instructed that the prime that they see (referred to as the "flashed word") is *not* the answer to the definition. Therefore, the instructions specifically warned participants against using the prime word as the correct answer to the definition and the multiple-choice task.

Results

Retrieval State Declaration. The mean percentage of retrieval states are displayed in the second panel in Figure 4. As shown here, the results from the state declaration nicely replicate those from Experiment 1.

First, consider the "know" responses. The ANOVA again revealed a main effect of prime condition, $F_1(3,186) = 11.45$, $p < .001$, $\eta_p^2 = .16$; $F_2(3, 297) = 14.37$, $p < .001$, $\eta_p^2 = .13$, no effect of age group by-participants ($F_1 = 1.43$), but a main effect by-items, $F_2(1,99) = 9.39$, $p = .003$, $\eta_p^2 = .09$, and no interaction ($F_1 = 1.94$; $F_2 = 2.13$). As in Experiment 1, the main effect of prime reflected a higher percentage of "know" responses in the "both" ($p < .001$), phonological ($p < .001$), and semantic ($p < .001$) conditions, compared to the unrelated condition. Item analyses also revealed that older adults reported greater percentage of "know" responses, compared to younger adults ($p = .003$).

The ANOVAs on the "don't know" yielded a main effect of prime condition, $F_1(3,186) = 8.54$, $p < .001$, $\eta_p^2 = .12$; $F_2(3, 297) = 9.76$, $p < .001$, $\eta_p^2 = .09$, a main effect of age group, $F_1(1,62) = 16.55$,

$p < .001$, $\eta_p^2 = .21$; $F_2(1,99) = 110.6$, $p < .001$, $\eta_p^2 = .53$, and no interaction ($F_1 = 1.72$; $F_2 = 1.49$). This result mainly indicated greater percentage of "don't know" responses in the unrelated condition, compared to the "both" ($p < .001$), phonological ($p < .001$), and semantic ($p < .001$) conditions, and also greater percentage of "don't know" responses in older adults compared to younger adults ($p < .001$), again mirroring the "know" responses and mimicking the results from Experiment 1.

Turning to the "other" responses, the ANOVA revealed a main effect of age group, $F_1(1,62) = 60.39$, $p < .001$, $\eta_p^2 = .49$; $F_2(1,99) = 201.2$, $p < .001$, $\eta_p^2 = .67$, no effect of prime condition ($F_1 = 1.45$; $F_2 = 1.45$) and no interaction ($F_1 < 1$; $F_2 < 1$). The main effect of age indicates that younger adults report more "other" responses than older adults ($p < .001$).

For the TOT responses there was a main effect of age group, $F_1(1,62) = 20.1$, $p < .001$, $\eta_p^2 = .24$; $F_2(1,99) = 103.5$, $p < .001$, $\eta_p^2 = .51$, no effect of prime condition ($F_1 = 1.28$; $F_2 = 1.56$), and no interaction ($F_1 < 1$; $F_2 < 1$). This result mainly indicated a greater percentage of "TOT" responses reported by younger adults, compared to older adults ($p < .001$). The analysis of TOTs as a proportion of unsuccessful retrievals (as described in Experiment 1) also revealed a main effect of age group, $F_1(1,62) = 12.7$, $p = .001$, $\eta_p^2 = .17$; $F_2(1,99) = 63.9$, $p < .001$, $\eta_p^2 = .39$, no effect of prime condition ($F_1 < 1$; $F_2 < 1$), and no interaction ($F_1 < 1$; $F_2 < 1$)[1].

Target Retrieval Accuracy. Figure 5 (Panel 2) displays the mean accuracy for each prime condition, for younger and older adults. A 2 (Age Group: Young, Old) x 4 (Prime Condition: "Both", Phonological, Semantic, Unrelated) ANOVA yielded a main effect of prime condition, $F_1(3, 186) = 8.84$, $p < .001$, $\eta_p^2 = .12$; $F_2(3, 297) = 18.75$, $p < .001$, $\eta_p^2 = .16$, no main effect of age by participants ($F_1 < 1$), but a significant effect of age group by items, $F_2(1,99) = 9.91$, $p = .002$, $\eta_p^2 = .09$. Overall, phonological primes again produced higher target retrieval accuracy than semantic primes, $t(63) = 3.81$, $p < .001$, "both" primes, $t(63) = 2.69$, $p = .009$, and unrelated primes, $t(63) = 4.64$, $p < .001$.

Further, "both" primes produced higher retrieval accuracy than unrelated primes, $t(63) = 2.21$, $p = 0.030$, and there were no differences between the other prime conditions.

In order to again account for differences in the strength of the phonological relations between the phonological and "both" primes, we again examined the effect of prime condition on target retrieval accuracy, after accounting for the composite, as described in Experiment 1. A one-way analysis of covariance (ANCOVA) revealed a main effect of prime condition, after controlling for the composite, $F_2(1,97)= 13.76$, $p < .001$, and a main of the composite, $F_2(1,97) = 5.69$, $p = .019$. These results replicate the findings from Experiment 1 and indicate that the differences in target accuracy between the phonological and "both" primes persist even after accounting for phonological/orthographic overlap with the target word. Hence, the presence of semantic information in the "both" condition appears to reduce the benefits of phonological priming.

Multiple-choice. Table 2 displays the mean accuracy in the multiple-choice test, as well as the proportion of incorrect options chosen for each prime condition. A 2 (Age Group: Young, Old) x 4 (Prime Condition: "Both", Phonological, Semantic, Unrelated) ANOVA revealed a main effect of age, $F_1(1, 62) = 4.89$, $p = .031$, $\eta_p^2 = .07$; $F_2(1, 99) = 24.59$, $p < .001$, $\eta_p^2 = .19$, a main effect of prime condition on multiple-choice accuracy, $F(3, 186) = 5.41$, $p = .001$, $\eta_p^2 = .08$; $F_2(3, 297) = 4.68$, $p = .003$, $\eta_p^2 = .04$, and a reliable interaction between age group and prime type, $F_1(3, 186) = 3.32$, $p = .021$, $\eta_p^2 = .05$; $F_2(3, 297) = 3.4$, $p = .018$, $\eta_p^2 = .03$. Follow-up comparisons revealed that younger adults were more accurate than older adults, when presented with phonological, $t(57.6) = 2.75$, $p = .007$, "both", $t(52.4) = 2.66$, $p = .010$, and semantic primes, $t(59.3) = 1.99$, $p = .050$. However, accuracy in the unrelated prime condition did not differ between the age groups.

Next, we analyzed the proportion of errors participants made in the multiple-choice task as a function of the prime that they received. A 2 (Age Group: Young, Old) x 4 (Prime Given: "Both",

Phonological, Semantic, Unrelated) x 4 (Prime Chosen: "Both", Phonological, Semantic, Unrelated) ANOVA for the proportion of errors as a function of the prime received, yielded a main effect of the prime chosen, $F_1(3, 186) = 549.81$, $p < .001$, $\eta_p^2 = .89$; $F_2(3, 297) = 117.1$, $p < .001$, $\eta_p^2 = .54$, a main effect of age group by participants, $F_1(1, 62) = 27.79$, $p < .001$, $\eta_p^2 = .30$, but no main effect of age group by items ($F_2 < 1$). We also observed no main effect of prime type. Importantly, the main effects were qualified by a highly significant three-way interaction among age group, the prime chosen and the prime given, $F_1(9, 558) = 5.96$, $p < .001$, $\eta_p^2 = .08$; $F_2(9, 891) = 4.64$, $p < .001$, $\eta_p^2 = .04$. Follow-up comparisons revealed that when presented with a related prime and explicit instructions that the prime was **not** the answer to the definition, older adults still chose the semantic, $t(51.6) = 2.7$, $p = .009$, and "both" primes, $t(61.9) = 2.31$, $p = .024$, consistently more often than younger adults. As predicted, it appears that older adults are relatively less able to control the primes, compared to younger adults, when explicitly warned.

To further examine the age-related differences in performance on the multiple-choice task across Experiments 1 and 2, we conducted a four-way, between-experiment ANOVA with experiment, age group, prime given and prime chosen, for the proportion of errors made in the multiple-choice, as a function of the prime received. This analysis yielded a reliable four-way interaction, $F_1(9, 1188) = 1.91$, $p = .046$, $\eta_p^2 = .01$; $F_2(9, 3168) = 2.38$, $p = .011$, $\eta_p^2 = .007$. Planned comparisons revealed that instructions had a significant effect on the performance of younger adults. When presented with a semantic prime, younger adults were less likely to choose it, when given explicit instructions that it was not the answer (Experiment 2) than when they were given no instructions (Experiment 1), $t(59.1) = 2.19$, $p = .032$. Similarly, younger adults chose the "both" prime less frequently when given explicit instructions in Experiment 2, compared to Experiment 1, $t(63.7) = 3.8$, $p < .001$. On the other hand, there was no effect of instruction on the performance of older adults when given semantic or "both"

primes, $p > .05$. These findings suggest an age-related difference in controlling prime information in response to explicit instructions.

Discussion

Results from Experiment 2 indicate that there is still reliable facilitation in the phonological and "both" conditions in word retrieval even when participants are explicitly warned that the prime is not the correct answer, and age does not modulate this pattern. This suggests that the influence of the primes may indeed reflect a more automatic activation of phonological information, consistent with the transmission-deficit hypothesis. In addition, these results indicated that there is more facilitation in the phonological condition, compared to the "both" condition. This pattern of phonological facilitation persisted after controlling for ratings on the phonological dimension and orthographic overlap (via the composite), replicating our results from Experiment 1, and further confirming that this latter effect is not attributable to differences in phonological/orthographic overlap between primes and targets.

Turning to the retrieval state declaration data, there is again a clear replication of the results from Experiment 1. Specifically, we again found that any relation between the prime and answer to the definition ("both", semantic and phonological) yielded an increase in reported "knowing" the answer, compared to the unrelated condition. Again, we found false feeling of knowing the answer in the semantic condition, since retrieval accuracy did not differ between the semantic and unrelated conditions. Second, we again found that older adults reported fewer "other responses" compared to younger adults. Clearly, this is inconsistent with an age-related increase in blocking or persistent alternates, as suggested by the inhibition deficit hypothesis.

Interestingly, administering instructions about the prime word not being the correct answer differentially influenced younger and older adults in the multiple-choice task. Specifically, while younger adults were able to respond to instructions and avoid the prime word as the answer on

incorrect trials, older adults did not control the prime information under explicit instructions to do so, and continued to choose the given prime (in the "both" and semantically related conditions) as the answer to the immediate multiple-choice test. Thus, although age did not modulate explicit target retrieval in this study, the results from the multiple-choice test indicate that older adults are less able to discriminate the source of a recently activated representation, when presented with the target and the prime alternatives in a multiple-choice test, consistent with the findings in Logan and Balota (2003).

Experiment 3

An important question that arises from Experiments 1 and 2 involves the underlying mechanism that produces the relatively larger interference effect from the primes on the multiple-choice test in older adults when they were explicitly instructed that the prime is not the correct answer. It is possible that under these conditions, older adults have persistent activation from the prime, but cannot attribute the source of that activation to the prime, i.e., a type of source-discrimination problem. In order to address this possibility, following Logan and Balota (2003), we conducted an experiment with younger adults with primes that were briefly presented (48 ms) near awareness threshold. If the prime is presented at threshold, then even younger adults should not be able to attribute any persistent activation to the prime, hence, they should increase their false alarm rate to the presented prime. In this way, we are testing the possibility that younger adults with threshold prime presentation will look more like older adults with suprathreshold prime presentation, and hence increase their false alarm rate to similar levels for the presented primes, as the older adults in Experiment 2.

Experiment 3 had three goals. First, if the phonological facilitation effect observed in the previous two experiments is indeed automatic, then we should find phonological facilitation under conditions in which the primes are briefly presented at a threshold level. While picture-word interference paradigms have used masked primes to demonstrate the influence of semantic competition

on naming (Finkbeiner & Caramazza, 2006; Piai et al., 2012), we are unaware of any studies that have used such briefly presented primes in explicit lexical retrieval from low-frequency word definitions. Second, if the prime influence is automatic, then one would also expect to replicate the effect of briefly presented primes on the metacognitive retrieval judgments, i.e., reporting more "know" responses after related primes, compared to unrelated primes. Third, as noted above, if the reduction in younger adults' false alarm rates to the presented primes in Experiment 2, compared to Experiment 1, is due to younger adults being able to consciously avoid the prime on the multiple-choice test, since they were explicitly told it could not be the target, then we should actually find an increase in the false alarm rates to the briefly presented primes, compared to the suprathreshold primes in Experiment 2. Specifically, the younger adults under masked conditions should look similar to the older adults in the unmasked conditions of Experiment 2 in their multiple-choice errors.

Method

Participants. Participants were thirty-six young adults (M_{age} = 20 years, *SD* = 3.5), undergraduates at Washington University in St. Louis, who were either paid or given course credit for their participation. Mean score on the Shipley Vocabulary test was 33.14 (*SD* = 3.00) and mean years of education was 13.89 (*SD* = 1.5). All participants except two were native English speakers, and the two non-native speakers were at or above the mean on the Shipley and performed well within normal performance on the experimental tasks. The study was approved by the Institutional Review Board at Washington University in St Louis.

Materials and Procedure. Materials and procedures were identical to those used in Experiments 1 with one exception. Primes following the definitions were presented for 48 ms instead of 300 ms, and were immediately followed by the definition for the target word[2]. As described in Footnote 2, the 48 ms prime duration was highly effective in minimizing prime identification even

under conditions in which participants directly attended to the prime information. Participants were given no instructions about the prime.

Results

Retrieval State Declaration. Figure 4 (bottom panel) displays the percentage of trials for each retrieval state. As shown here, the results from the younger adults with very short duration primes is very similar to the younger adult data in Experiments 1 and 2. Specifically, for "know" responses, there was again a main effect of prime condition, $F_1(3,105) = 4.67$, $p = .004$, $\eta_p^2 = .12$; $F_2(3, 297) = 9.82$, $p < .001$, $\eta_p^2 = .09$. This result indicates a higher percentage of "know" responses in the "both" ($p = .002$), phonological ($p = .013$), and semantic ($p < .001$) conditions, compared to the unrelated condition, replicating the false knowing response observed in the earlier experiments.

As expected, the "don't know" response mirror the "know" responses. The ANOVA produced a main effect of prime condition, which reflected a higher percentage "don't know" responses in the unrelated condition, compared to the "both" ($p = .007$), phonological ($p = .059$), and semantic ($p = .003$) conditions. Hence, as in the previous experiments, there is a clear influence of prime relatedness on metacognitive judgements of "know" and "don't know" retrieval states.

Consistent with Experiment 2, the effect of prime condition did not approach significance for the "other" responses ($F_1<1$; $F_2<1$)[1]. For TOT responses, there was a main effect of prime condition by-participants, $F_1(3,105) = 2.71$, $p = .049$, which approached significance by items, $F_2(3, 297) = 2.47$, $p = .062$. This result indicated slightly higher percentage of TOT responses following unrelated primes, compared to semantic ($p=.004$) and "both" ($p=.045$) primes. The analysis of TOTs as a proportion of unsuccessful retrievals (as in Experiments 1 and 2) revealed no effect of prime condition by participants ($F_1= 1.94$), and a marginal effect by-items, $F_2 (3,297) = 2.25$, $p = .083$. This effect mainly

indicated marginally lower proportion of TOTs in the semantic condition, compared to the phonological (p = .036), and unrelated conditions (p=.027).

Target Retrieval Accuracy. Figure 5 (Panel 3) displays the mean accuracy for each prime condition. A one-way ANOVA revealed a significant effect of prime type on target retrieval accuracy, $F_1(3, 105) = 2.93$, $p = .037$, $\eta_p^2 = .07$; $F_2(3, 297) = 5.56$, $p < .001$, $\eta_p^2 = .05$. Follow-up comparisons revealed that retrieval accuracy in the phonological prime condition was significantly higher than the semantic prime condition, $t(35) = 2.21$, $p = 0.033$, and the unrelated prime condition, $t(35) = 3.05$, $p = .004$. As shown in Figure 5, as in the previous experiments, the "both" prime fell in between the phonological condition (p = .19), and the semantic (p = .32) and unrelated conditions (p = .18), although these differences were not reliable. Additional analyses have been reported in Sections 1, 2 and 3.1 in Supplementary Materials.

To account for differences in the strength of the phonological relations between the phonological and "both" primes, we again examined the effect of prime condition on target retrieval accuracy, after accounting for the composite, as described in Experiment 1. A one-way analysis of covariance (ANCOVA) revealed a marginal effect of prime condition, after controlling for the composite, F_2 (1,97)= 3.39, p = .068, and no main effect of the composite, $F_2(1,97) = .358$, p = .551. These results indicate that the difference between the phonological and "both" primes in not reliable when primes are presented for very brief durations.

Multiple-choice. Table 3 displays the mean accuracy in multiple-choice questions, as well as the proportion of incorrect options chosen for each prime condition. A one-way ANOVA revealed a significant main effect of prime type on multiple-choice accuracy, $F_1(3, 105) = 3.29$, $p = .024$, $\eta_p^2 = .08$; $F_2(3, 297) = 3.23$, $p = .022$, $\eta_p^2 = .03$. Accuracy in the semantic prime condition was significantly

lower than accuracy in the unrelated prime condition, $t(35) = 2.80$, $p = .007$, and in the phonological prime condition, $t(35) = 2.31$, $p = .027$.

Next, we analyzed the proportion of errors participants made in the multiple-choice task as a function of prime type. A 4 (Prime Given: "Both", Phonological, Semantic, Unrelated) x 4 (Prime Chosen: "Both", Phonological, Semantic, Unrelated) ANOVA revealed a main effect of prime chosen, $F_1(3, 105) = 448$, $p < .001$, $\eta_p^2 = .92$; $F_2(3, 297) = 99.94$, $p < .001$, $\eta_p^2 = .50$, qualified by a significant interaction between prime given and prime chosen, $F_1(9, 315) = 6.86$, $p < .001$, $\eta_p^2 = .16$; $F_2(9,89) = 7.141$, $p < .001$, $\eta_p^2 = .07$. Planned comparisons revealed that "both" and semantic primes were chosen more often than phonological and unrelated primes in all prime conditions. Importantly, when given a semantic prime, participants chose the semantic prime significantly more often than the "both" prime, $t(35) = 6.33$, $p < .001$, and when given a "both" prime, they chose the "both" prime more often than the semantic prime, although this trend was not significant, $p = .35$.

Finally, we compared the performance of younger adults in Experiment 3 on the multiple-choice task with the performance of older adults in Experiment 2. A 2 (Experiment: 2, 3) x 4 (Prime Given: "Both", Phonological, Semantic, Unrelated) x 4 (Prime Chosen: "Both", Phonological, Semantic, Unrelated) ANOVA revealed no hint of a three-way interaction between experiment, prime given and chosen prime ($F_1 < 1$; $F_2 < 1$), which suggests that the performance of younger adults under threshold priming conditions was similar to older adults in Experiment 2 in the multiple-choice task. We also compared the performance of younger adults in Experiment 2 with younger adults in Experiment 3, and observed a highly significant interaction among experiment, prime given and chosen prime, $F_1(9, 594) = 9.54$, $p < .001$, $\eta_p^2 = .12$; $F_2(9, 891) = 8.44$, $p < .001$, $\eta_p^2 = .08$. Figure 5 displays the proportion of error trials in which the "both" and semantic primes were chosen, when participants saw semantic and "both" primes, across Experiments 2 and 3. This overall pattern

indicates that younger adults with explicit instructions (Experiment 2) are able to modulate their performance and not choose the prime that they saw, whereas older adults with instructions (Experiment 2) and younger adults under threshold priming conditions (Experiment 3) are unable to do so. Indeed, as shown in the two leftmost panels of Figure 6, older adults with instructions to ignore the prime look remarkably similar to younger adults given threshold primes, replicating the pattern observed by Logan and Balota (2003) in a primed fragment completion paradigm.

Discussion

Results from Experiment 3 suggest that lexical retrieval is reliably facilitated by a brief 48 ms presentation of a phonological prime. In addition, the activation produced by this brief presentation of related information influences the likelihood of reported "knowing" the correct response (false "knowing" in the related condition), and even has lingering, and relatively, large effects on the immediate multiple-choice test. Importantly, the multiple-choice results indicate that younger adults are even more influenced by the prime information under the threshold conditions of Experiment 3, compared to the clearly suprathreshold conditions of Experiment 2, and now look very much like the older adults in Experiment 2. We believe that this is most likely due to failure during the multiple-choice test of attributing the source of the familiarity to the prime, as opposed to the retrieval processes engaged by the low-frequency word definition.

General Discussion

The present study explored the influence of briefly presented primes after a low-frequency word definition on metacognitive declarations of retrieval state, retrieval accuracy, and immediate multiple-choice accuracy in young and older adults. We discuss the implications of each of these three findings below.

Retrieval Accuracy

The present results indicate that the brief presentation of a phonologically related word facilitates the retrieval of a subsequent target word to a low-frequency word definition, compared to semantically related and unrelated words. Phonological facilitation in target retrieval accuracy was observed across both age groups (Experiments 1 and 2), and when primes were presented for 300 ms (Experiments 1 and 2), and for 48 ms (Experiment 3, younger adults only). In addition, the phonological information in the "both" prime was sufficient to produce facilitation in Experiments 1 and 2, but did not reach significance when the prime was briefly presented in Experiment 3. Overall, the phonological facilitation in the "both" condition was smaller than in the pure phonological condition and the covariate analyses that accounted for differences in phonological strength and orthographic overlap between the primes mirrored these results, and further confirmed this difference in facilitation between the phonological and "both" primes.

These results are consistent with previous studies that show that exposure to phonology facilitates subsequent target retrieval. For example, James and Burke (2000) primed participants with lists of words that cumulatively contained all the syllables of the target word (e.g., for the target, *abdicate*, participants first pronounced a list of 10 words, including the following 5 words: *ab*stract, in*di*gent, trun*cate*, tra*di*tion, and loc*ate*). They found that syllable priming facilitated correct retrieval and decreased TOT states. Other studies have also shown that internal or overt production of phonology (Abrams, White & Eitel, 2003), presentation of phonological cues (Meyer & Bock, 1992), and syllable priming (White & Abrams, 2002) resolve retrieval failures. Furthermore, the phonological priming effect appears to be fairly stable across age groups, such that age does not interact with priming (James & Burke, 2000), except in the case of old-old (aged 73-83 years) adults (White & Abrams, 2002). The present experiments converge with previous literature and show that both younger

and older adults experience phonological facilitation in target retrieval accuracy not only in the phonological condition, but also in the "both" condition.

A critical aspect of the present set of experiments is the inclusion of prime words that shared *both* semantic and phonological information with the target (i.e., the "both" primes). While Jones (1989) used "both" primes in a lexical retrieval task and found that primes related in phonology produced greater TOTs than related and unrelated primes, Meyer and Bock (1992) showed that these results were a result of a failure to counterbalance target items and primes. As discussed previously in the introduction, to our knowledge, there are only two other studies that have explored the influence of primes which include *both* semantic and phonological information, and so we now provide a brief discussion of how the present results add to these previous studies.

Oberle and James (2013) examined the influence of presenting "both" primes that shared the full first name with the target word on retrieving proper names. They found that prior exposure to "both" primes led to increased correct responses to a target celebrity photo, and also reduced the incidence of TOT states. However, it is unclear if the "both" primes in the Oberle and James (2013) study reflected semantic, phonological information or lexical information since the full first name was presented as the primes in the "both" condition. Moreover, Oberle and James (2013) did not include primes that shared *only* phonological or *only* semantic information with the target, so it is unclear whether the facilitation observed in their experiments is solely due to the influence of phonology or semantics, or both. Our results suggest that the observed facilitation is likely due to the overlap in phonological information in the "both" primes, since we observed facilitation in the "both" condition in our experiments, compared to either the semantically related or unrelated conditions. Indeed, studies on picture naming have shown that semantically related words may in fact diminish phonological

priming (Abdel Rahman & Melinger, 2008; Cutting & Ferreira, 1999). We will return to this issue below.

White, Abrams and Frame (2013) showed that "both" primes can in fact moderate the effect of phonology. They presented participants with target definitions, followed by primes that were "both", phonological or unrelated to the target word. As previously discussed, their results showed that participants were less likely to resolve TOTs following exposure to a "both" prime that shared only the first syllable with the target, compared to first-syllable phonological primes, suggesting that semantic overlap reduced the ability of shared phonology to facilitate TOT resolution.

The present study differed from the previous two studies in a number of important ways. First, in addition to the prime conditions they used, we also included primes that are *only* semantically related to the target, allowing us to measure the effect of "both" primes relative to primes that overlap with the target *only* in phonology or *only* in semantics. Second, our pilot data indicates that our "both" primes had a high degree of both phonological and semantic relatedness, similar to the *only* phonological and *only* semantic primes, albeit a bit smaller. Third, our phonological and "both" primes primarily shared the first syllable with the target, given that the initial onset may be particularly important in lexical retrieval (Forster & Davis, 1991). Fourth, in addition to probing participants for TOT states, we also asked participants if they had any other words in mind. This allowed us to explicitly test for the presence of "blocking" words, thus differentiating between a deficit in transmission of priming (Burke, MacKay, Worthley & Wade,1991) vs. blocked access to the target word (Jones, 1989; Zacks, Hasher & May, 1990). Our results provide no evidence of "blocking" for any prime types or age groups, since participants were equally likely to choose the TOT and "other word in mind" to characterize their retrieval state across prime types (see Figure 4). Finally, it is noteworthy that our results also show that primes that overlapped *only* in phonology produced

facilitation in target retrieval, even when these primes were presented for very short durations (48 ms, Experiment 3).

Interestingly, primes that shared "both" phonology and semantics with the target fell between *only* phonological and *only* semantic or unrelated primes. Indeed, a one-way ANOVA on target retrieval accuracy, collapsed across experiments and age groups (which did not interact with prime type), revealed that participants benefited most from *only* phonological primes, compared to semantic, $t(171) = 7.81$, $p < .001$, "both", $t(171) = 4.91$, $p < .001$, and unrelated primes, $t(171) = 8.86$, $p < .001$. Importantly, the "both" primes did produce reliable facilitation, relative to semantic, $t(171) = 2.79$, $p = .006$, and unrelated primes, $t(171) = 3.42$, $p < .001$. Further, semantic primes did not differ from unrelated primes, $t(171) = 0.59$, $p = .554$, suggesting that pure semantic information does not facilitate target retrieval. Thus, our results clearly indicate that although reduced, there still is a facilitatory effect of the phonology in the "both" primes compared to the semantic and unrelated primes. Importantly, as shown by our covariance analyses, this reduced facilitation from the "both" prime, compared to the phonological prime, persists after controlling for phonological ratings and orthographic overlap between the prime and target. Thus, it appears that the strength of the shared semantic information between the "both" prime and the target is critical in determining the amount of facilitation observed in subsequent target retrieval.

Given that we obtained estimates of ratings of the semantic and phonological overlap, and Levenshtein distances between the prime and target for each individual pair, we were able to examine if the degree of strength of the relationship on semantic or phonological levels is predictive of the facilitation and/or inhibition observed in target retrieval. In order to examine this at an item level, we used generalized linear mixed models (with a logit link) from the lme4 package (Bates & Sarkar, 2006) in the RStudio environment (R version 3.4.2 (2017-09-28), R Development Core Team, 2006) to

examine the relationship between prime-target association ratings, Levenshtein distances, and retrieval accuracy. Figure 7 displays the predicted probabilities for target retrieval accuracy as a function of the rating given to the prime-target semantic or phonological association, for different levels of item difficulty[3], across all experiments (see Table 4 for the best-fitting model estimates). Importantly, we observed that higher ratings of prime-target association on the phonological dimension produced higher target retrieval accuracy. In contrast, higher ratings on the semantic dimension produced ***lower*** target retrieval accuracy. Note that, interestingly, the pattern for the "both" prime was similar to the phonological prime when rated on phonology, and similar to the semantic prime, when rated on semantics, further suggesting that attention to a particular dimension (e.g., sound or meaning-based) between the prime and target has differential influences on lexical retrieval.

These analyses provide further insight into the combined influence of phonology and semantics in the "both" condition on retrieval processes. Given the reduced facilitation from "both" primes, compared to the purely phonological primes, and the inverse relationship of semantic strength with target retrieval accuracy in the item analyses, these results suggest that semantic association can modulate the benefits of phonological information. The inhibitory effect of strong semantic overlap between the distractor and target word has been previously reported in lexical retrieval picture naming tasks (Finkbeiner & Caramazza, 2006; Starreveld & La Heij, 1995). Hence, it is possible that if we used strong associates that this would totally eliminate any phonological facilitation. It should also be noted that our results are consistent with those of White, Abrams and Frame (2013) for the first-syllable primes, which provided clear evidence that overlapping semantic information likely introduces some degree of competition into the lexical selection process, leading to a reduced likelihood of successful lexical retrieval, compared to the phonological prime condition. This pattern of results is most consistent with a spreading-activation/transmission-deficit framework, according to which

phonological overlap facilitates retrieval by activating the phonological codes. At the same time, semantic relationships can produce sufficient competition with the target node (as described by Piai, Roelofs & Schriefers, 2012; see also Finkbeiner & Caramazza, 2006) and hence hinder retrieval of that word.

State Declaration Results

Immediately after participants received the definitions and the primes, they reported their current retrieval state. In addition to "know" and "don't know" responses, participants could select a "TOT" response or "another word is coming to mind" response. There are a number of consistent and noteworthy effects in these state declaration results. First, compared to younger adults, older adults were more likely to rely on "know" or "don't know" responses than TOT or "another word coming to mind" responses. This difference in metacognitive reports diverges somewhat from studies that show that older adults experience more TOT states (Burke, MacKay, Worthley & Wade,1991; Heine, Ober & Shenaut, 1999). We believe that the inclusion of an immediate multiple-choice test may be important here. Specifically, older adults benefit from tasks that provide environmental support (e.g., multiple-choice) vs. those that do not (e.g., lexical retrieval, see Craik, 1983), and so older adults may simply rely more on "know" and "don't know" states in anticipation of receiving the correct answer in the multiple-choice. One can hypothesize that the state declarations of having another word in mind or being in a TOT state, require more cognitive effort than simply defaulting to either knowing or not knowing an answer almost immediately after reading the definition. Under this assumption, and the fact that the current paradigm involved and immediate multiple-choice test, affording environmental support, older adults may just be more likely to not reflect on their metacognitive retrieval state as much in this paradigm, and simply default to the immediate sense of "knowing" or "not knowing" an answer. Thus, because older adults know that they can simply choose the correct answer from the

immediately following multiple-choice task, they may be less likely to spend cognitive effort on more subtle state declarations and default to choosing only "know" and "don't know" retrieval states at the time of retrieval. Of course, this is a post-hoc account that would need a more direct test to examine this hypothesis.

Second, and importantly, there were consistent influences of prime type on the likelihood of participants selecting the "know" response. Specifically, participants were more likely to select the "know" response for primes that had any relation to the target answer compared to unrelated primes. This effect is particularly intriguing in the semantic condition, since this condition did not produce any benefit in lexical retrieval compared to the unrelated condition. This false "knowing" occurred across both age groups, under conditions in which participants were explicitly told that the primes were not the correct answer, and even for the very briefly presented primes in Experiment 3. It appears that participants believe that semantically related information will produce some benefit in lexical retrieval, even though there is no evidence that this is the case, and indeed there is evidence of inhibition from strong semantic associates based on the generalized linear mixed effects analyses.

Age-Related differences in Multiple-choice Selection

In addition to examining the influence of a single prime on target retrieval, and state declaration, an important third motivation for this study was to examine the influence of lingering prime information on subsequent performance on an immediate multiple-choice decision. We were mainly interested in exploring age-related differences in the ability to control distracting information produced by the prime item embedded in the multiple-choice query to select the correct answer. Our results demonstrate that the presentation of related information in the semantically related and "both" conditions increased false alarms to the prime item, compared to unrelated and phonological conditions. This effect occurred even when related information (primes) was presented very briefly, as

in Experiment 3, for the younger adults. Importantly, compared to younger adults, older adults were more likely to choose the prime they were given as the answer to the definition in the multiple-choice task, even when explicitly instructed that the prime was not the answer to the definition (Experiment 2). Results from Experiment 3, where younger adults were presented the primes at a threshold level, yielded similar results to the older adults in Experiment 2. We interpret these results to indicate that the ability to distinguish between the source of the activation of relevant (target) and irrelevant (prime) information is critical to performance in the multiple-choice task. Our findings are consistent with pattern previously reported by Logan and Balota (2003), such that older adults are specifically impaired at determining the source of activation when highly related information is available to them, even when provided with specific instructions against the use of the prime. As in Logan and Balota, we were able to mimic this pattern in younger adults, when the primes were presented near threshold. In addition, our results provide evidence that information that is related in both semantics and phonology (i.e., the "both" primes) not only reduces facilitation from phonology during lexical retrieval (as previously discussed), but also produces increased interference in a subsequent recognition task, especially in older adults.

A potential concern with the findings from the multiple-choice task is that the unrelated primes for the target words differed from the other primes on several dimensions (see Appendix). Thus, participants may easily identify the unrelated prime as an incorrect answer on the multiple-choice, leading to potential inflation in multiple-choice accuracy and errors made in the semantic and "both" conditions. However, we do not see any consistent differences in the likelihood of choosing the phonological and unrelated primes, specifically when participants did not receive these primes. This suggests that it is unlikely that participants were differentially choosing the phonological and unrelated primes in the multiple-choice, just based on item characteristics in the multiple-choice test.

Conclusion

The present experiments provide strong evidence for age-invariant phonological facilitation during lexical retrieval. Moreover, Experiment 3 indicates that such facilitation can occur with very brief durations in younger adults, and hence appears to be more automatic in nature. These results also suggest that the "both" prime does not produce as much facilitation as the phonological prime, implying that weak semantic information shared between the prime and target moderates the effect of phonology. We have also shown via generalized linear mixed models a clear positive relationship between phonological strength and successful target retrieval accuracy and a clear inhibitory effect of semantic strength and successful target retrieval. Finally, there were age-related differences in the persisting influence of competing information on an immediate multiple-choice test, such that older adults are disproportionately impaired at discounting persisting, but irrelevant information on a subsequent multiple-choice task. Given that this older adult pattern was mimicked in a study where younger adults received the primes with very brief presentation, we believe this latter effect most likely reflects a source discrimination deficit.

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Footnotes

[1]It is possible that separating being in a TOT state from having another alternate word in mind may influence our results, given that there are age-related differences in how often TOTs occur with alternate words. To address this issue, we collapsed the TOT and "other" responses into one measure, TOT/Alternate, and calculated the percentage occurrence of TOT/Alternate states for each prime type. In Experiment 1, a 4 (Prime-Type) x 2 (Age Group) ANOVA revealed a main effect of age group, $F_1(1,70) = 47.42$, $p < .001$, $\eta_p^2 = .40$; $F_2(1,99) = 158$, $p < .001$, $\eta_p^2 = .61$, a main effect of prime condition, $F_1(3,210) = 5.96$, $p = .001$, $\eta_p^2 = .08$; $F_2(3, 297) = 8.33$, $p < .001$, $\eta_p^2 = .08$, and no interaction ($F_1 < 1$; $F_2 < 1$), consistent with the analyses reported for TOT and "other" responses separately. Similarly, in Experiment 2, we again observed a main effect of age group, $F_1(1,62) = 71.19$, $p < .001$, $\eta_p^2 = .53$; $F_2(1,99) = 253.7$, $p < .001$, $\eta_p^2 = .72$, but also a main effect of prime condition, $F_1(3,186) = 3.02$, $p = .031$, $\eta_p^2 = .05$; $F_2(3, 297) = 3.09$, $p = .027$, $\eta_p^2 = .03$, and no interaction ($F_1 < 1$; $F_2 < 1$). Finally, in Experiment 3, we observed a main effect of prime condition, $F_1(3,189) = 3.05$, $p = .029$, $\eta_p^2 = .05$, which was marginal by items, $F_2(3, 297) = 2.21$, $p = .087$, $\eta_p^2 = .02$. Overall, consistent with the analyses reported in the main text of the manuscript, younger adults produce more TOT/Alternate responses compared to older adults, further indicating that the present age-related patterns were fairly reliable.

[2] In order to address the degree to which participants could read the primes in this context, we replicated the experiment and asked 12 young adults from the same participant pool to type in the prime word, instead of the correct answer to the definition. The experiment was identical to Experiment 3, but participants were asked to report the prime item. Importantly, participants could report the prime only on 24% of the total trials. As expected, there was also an influence of prime type

on prime reporting across the semantic (mean = 0.36), "both" (mean = 0.27), phonological (mean = 0.16) and unrelated (mean = 0.18) conditions, $F(3, 105) = 9.02$, $p < .001$. The relatively high levels of accuracy in the semantic and "both" conditions are likely due to participants being able to use the definitions and partial information from the degraded prime to guess the identity of the prime. The important point here is that even under ideal conditions in which participants were directly attending to the identity of the prime, instead of trying to come up with the answer to the definition, there was relatively low perceptibility. Of course, because attention is directed towards retrieving the correct answer to the definition in Experiments 3, prime perceptibility is likely overestimated in this control experiment. It is particularly noteworthy that the phonological prime produced the lowest accuracy and yet this is the condition that produced the largest priming effect in Experiment 3.

[3]To effectively display the three-way relationship between target retrieval accuracy, ratings and item accuracy, a categorical measure of item difficulty was computed, consisting of three levels: "easy", "medium" and "difficult". Based on the mean accuracy across all items, all items below 1 standard deviation of the mean accuracy were categorized as "difficult", and all items above 1 standard deviation were categorized as "easy". The remaining items were categorized as "medium" items. The item analyses used the actual item accuracy as an interval-type predictor.

Table 1

Multiple-choice accuracy and proportion of errors in Experiment 1.

			Prime Chosen			
	Prime Given	Mean Multiple-Choice Accuracy	Semantic	Phonological	Both	Unrelated
Young	Semantic	0.64	**0.57**	0.02	0.37	0.02
	Phonological	0.75	0.48	**0.05**	0.39	0.01
	Both	0.69	0.43	0.04	**0.51**	0.01
	Unrelated	0.69	0.53	0.03	0.4	**0.03**
Old	Semantic	0.64	**0.67**	0.01	0.23	0
	Phonological	0.72	0.46	**0.08**	0.35	0
	Both	0.66	0.39	0.02	**0.45**	0
	Unrelated	0.7	0.44	0.02	0.32	**0.07**

Note. Mean Multiple-Choice Accuracy scores were computed on the total number of trials, whereas scores for Prime Chosen reflect proportions computed on error-trials only.

Table 2

Multiple-choice accuracy and proportion of errors in Experiment 2.

			Prime Chosen			
	Prime Given	Mean Multiple-Choice Accuracy	Semantic	Phonological	Both	Unrelated
Young	Semantic	0.75	**0.42**	0.02	0.54	0.02
	Phonological	0.78	0.49	**0.03**	0.42	0.02
	Both	0.78	0.65	0.05	**0.29**	0.01
	Unrelated	0.69	0.55	0.04	0.39	**0.01**
Old	Semantic	0.67	**0.60**	0.03	0.26	0
	Phonological	0.67	0.47	**0.06**	0.37	0.01
	Both	0.69	0.47	0.04	**0.43**	0
	Unrelated	0.67	0.50	0.04	0.34	**0.03**

Note. Mean Multiple-Choice Accuracy scores were computed on the total number of trials, whereas scores for Prime Chosen reflect proportions computed on error-trials only.

Table 3

Multiple-choice accuracy and proportion of errors in Experiment 3.

			Prime Chosen			
	Prime Given	Mean Multiple-Choice Accuracy	Semantic	Phonological	Both	Unrelated
Young	Semantic	0.62	**0.67**	0.02	0.29	0.01
	Phonological	0.68	0.52	**0.06**	0.4	0.02
	Both	0.66	0.45	0.01	**0.52**	0.01
	Unrelated	0.68	0.5	0.05	0.44	**0.02**

Note. Mean Multiple-Choice Accuracy scores were computed on the total number of trials, whereas scores for Prime Chosen reflect proportions computed on error-trials only.

Table 4

Model estimates from the best-fitting generalized linear mixed model, predicting target retrieval accuracy from prime-target association ratings.

Model	Term	Predictor(s)	Estimate	95% Confidence Interval	Std. Error	z-value
Phonological (Sound Rating)	Fixed	Intercept	-3.24	(-4.23,-2.27)	0.49	-6.52
		Rating	0.10	(-0.10,0.31)	0.10	0.98
		Item Accuracy	5.56	(2.70,8.46)	1.46	3.81
		Rating*Item Accuracy	0.23	(-0.37,0.85)	0.31	0.76
	Random	Subject	1.13			
Semantic (Meaning Rating)	Fixed	Intercept	-2.32	(-3.29,-1.27)	0.48	-4.8
		Rating	-0.28	(-0.48,-0.08)	0.10	-2.74
		Item Accuracy	4.61	(1.94, 7.33)	1.36	3.38
		Rating*Item Accuracy	0.51	(-0.06,1.07)	0.28	1.78
	Random	Subject	1.05			
Both (Sound Rating)	Fixed	Intercept	-4.26	(-5.16,-3.38)	0.45	-9.52
		Rating	0.24	(0.05,0.43)	0.09	2.48
		Item Accuracy	8.52	(6.16,10.89)	1.19	7.16
		Rating*Item Accuracy	-0.44	(-0.95,0.08)	0.26	-1.68
	Random	Subject	0.89			
Both (Meaning Rating)	Fixed	Intercept	-2.86	(-2.74,-2.12)	0.38	-7.62
		Rating	-0.09	(-0.25,0.08)	0.08	-1.05
		Item Accuracy	7.14	(5.27,9.06)	0.96	7.43
		Rating*Item Accuracy	-0.09	(-0.49,0.31)	0.20	-0.46
	Random	Subject	0.89			

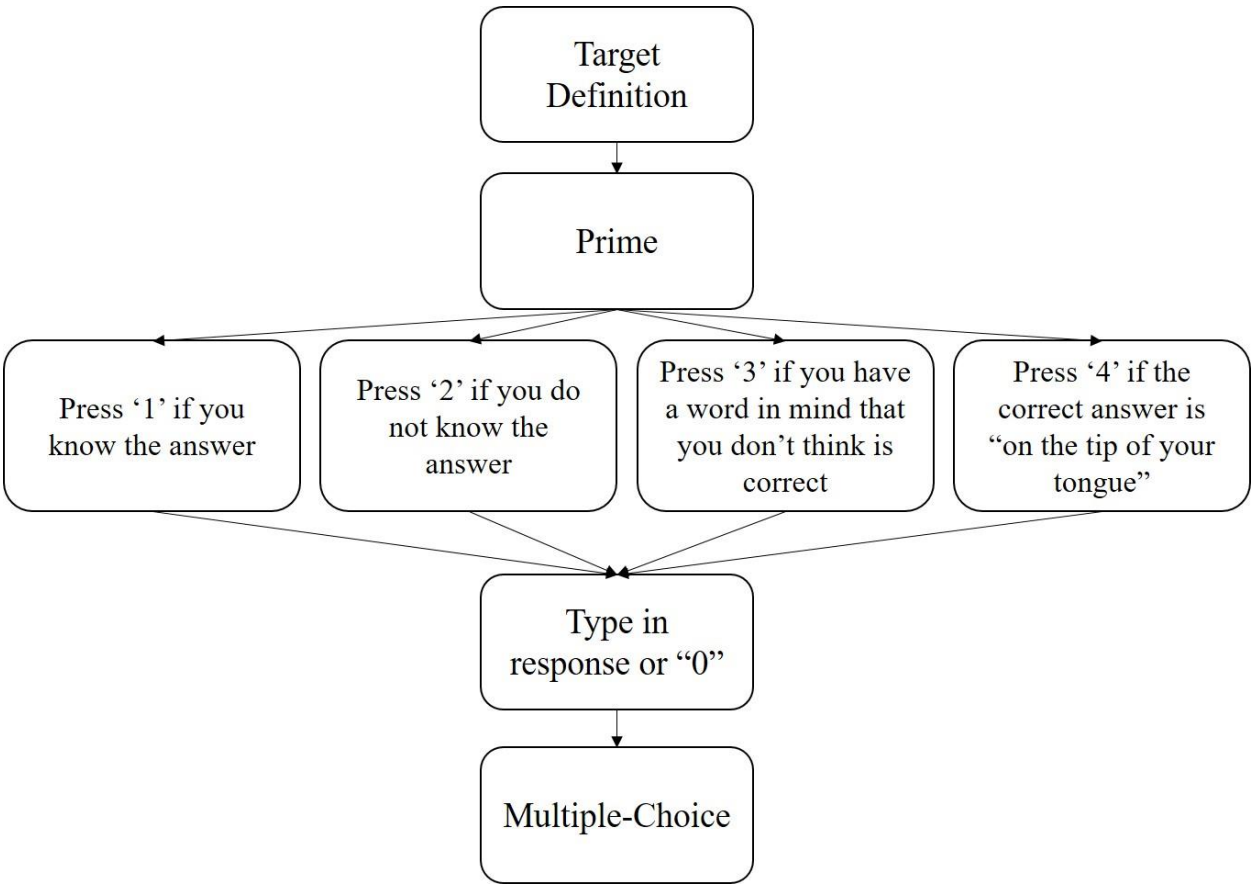

Figure 1. Experiment trial procedure.

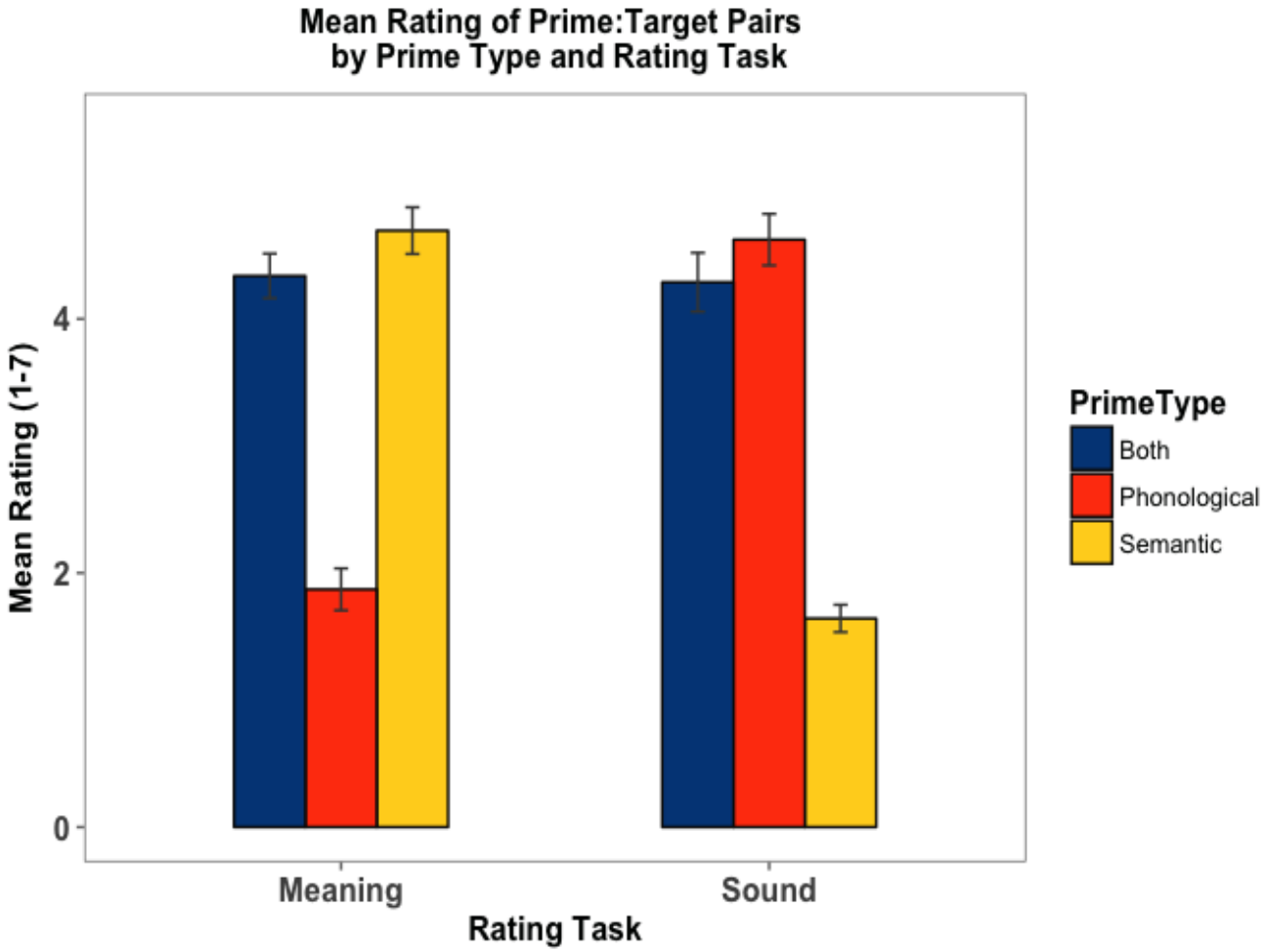

Figure 2. Mean ratings for PRIME:TARGET word pairs in sound and meaning-based rating task conducted on Amazon Mechanical Turk. Error bars represent standard errors of the mean

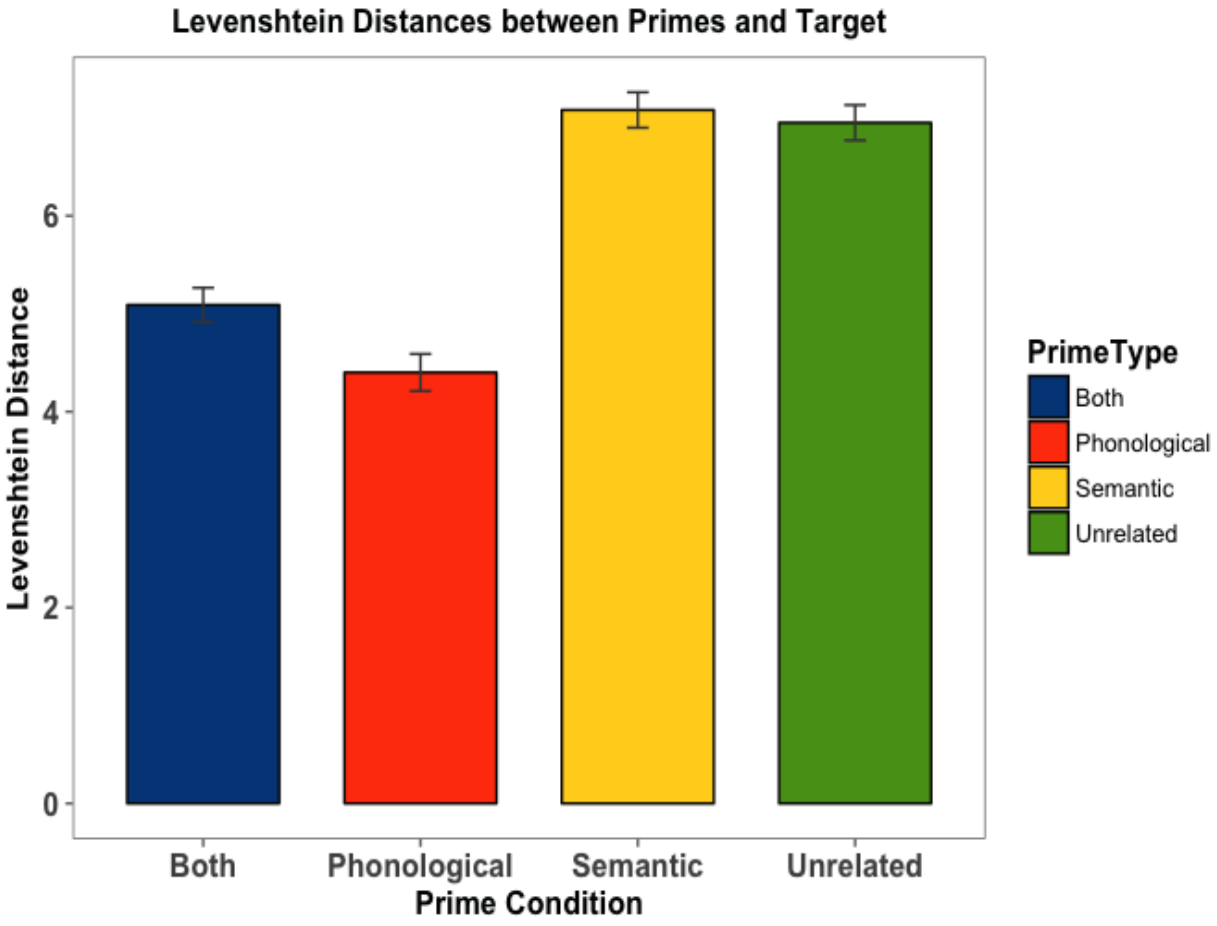

Figure 3. Mean Levenshtein distances for PRIME:TARGET word pairs. Error bars represent standard errors of the mean.

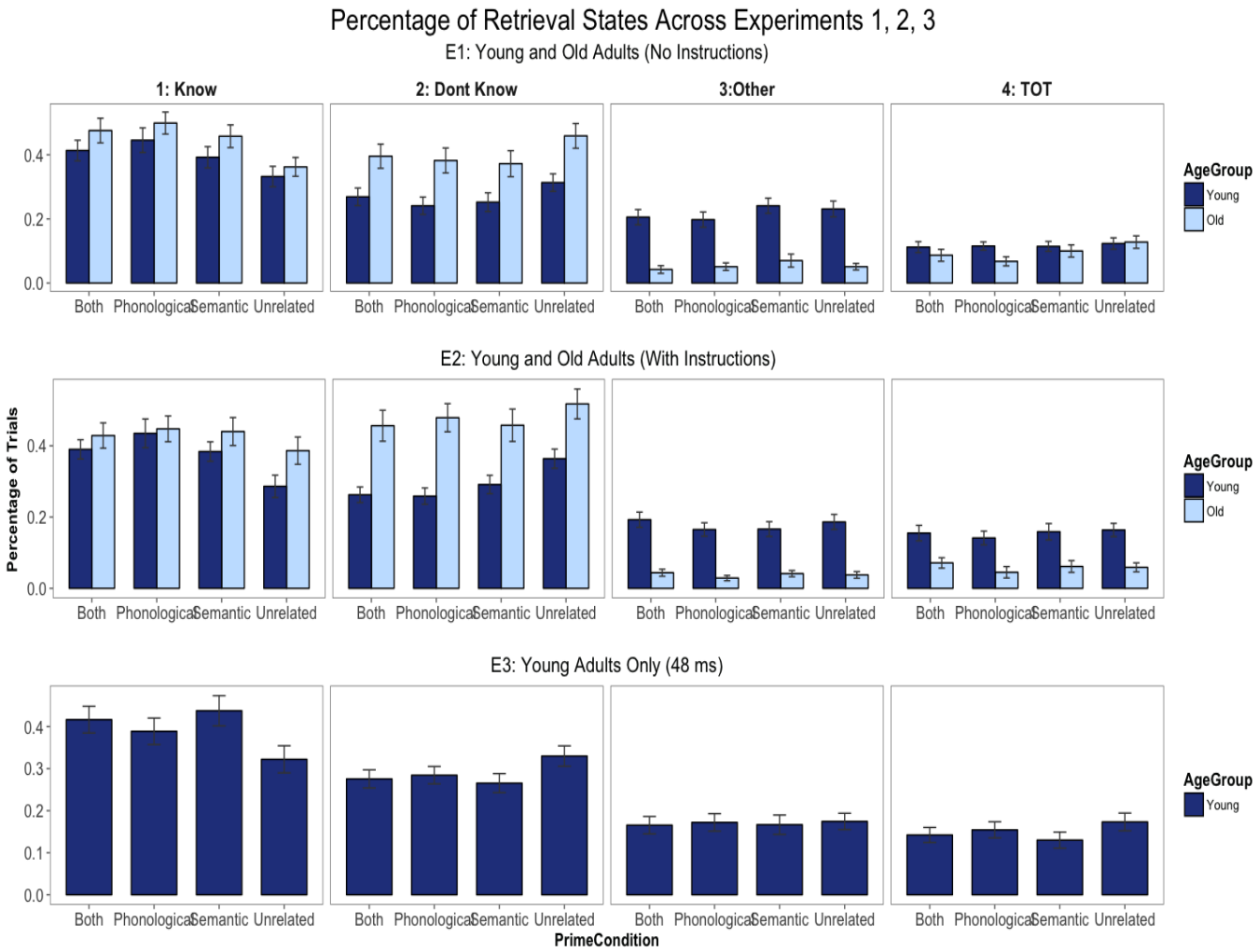

Figure 4. Retrieval state trials split across age in Experiments 1, 2 and 3. Error bars represent standard errors of the mean.

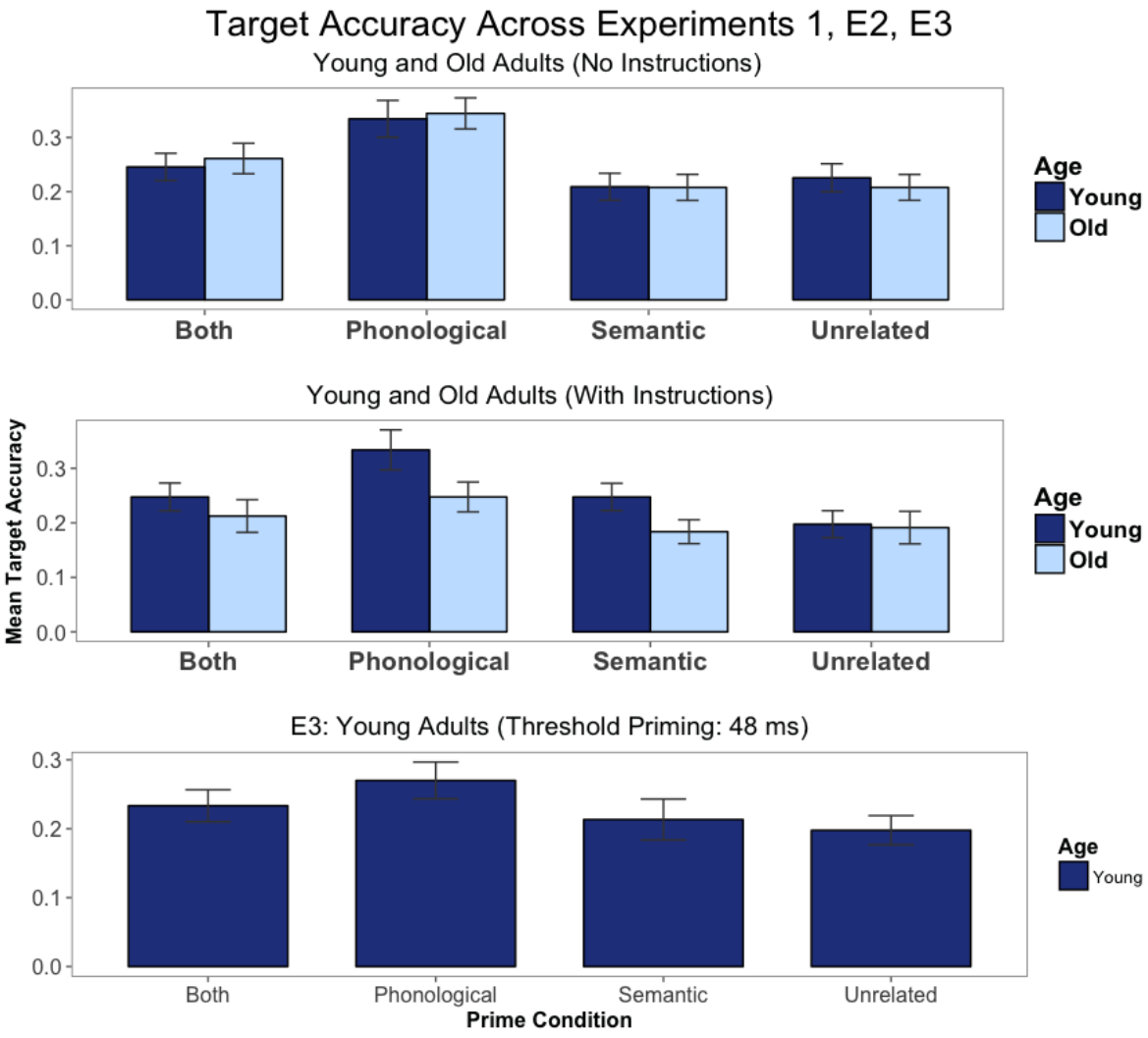

Figure 5. Target retrieval accuracy in Experiments 1, 2 and 3. Error bars represent standard errors of the mean.

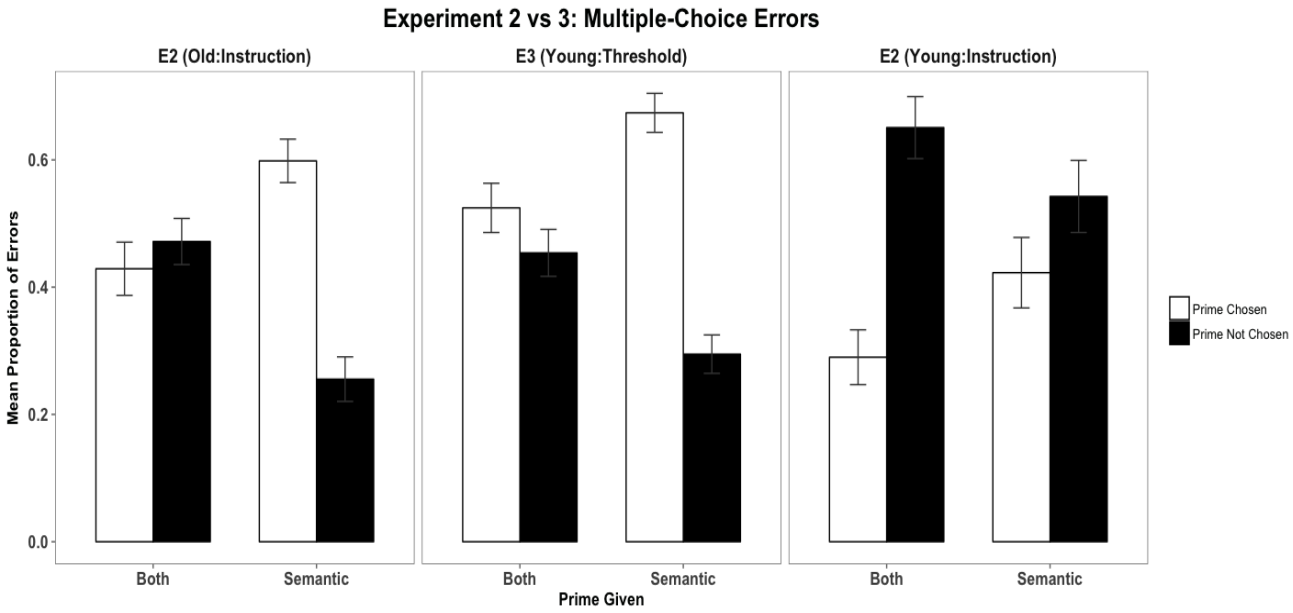

Figure 6. Comparing performance on the multiple-choice task in Experiments 2 and 3, for trials in which participants were given "both" and semantic primes. Error bars represent standard errors of the mean.

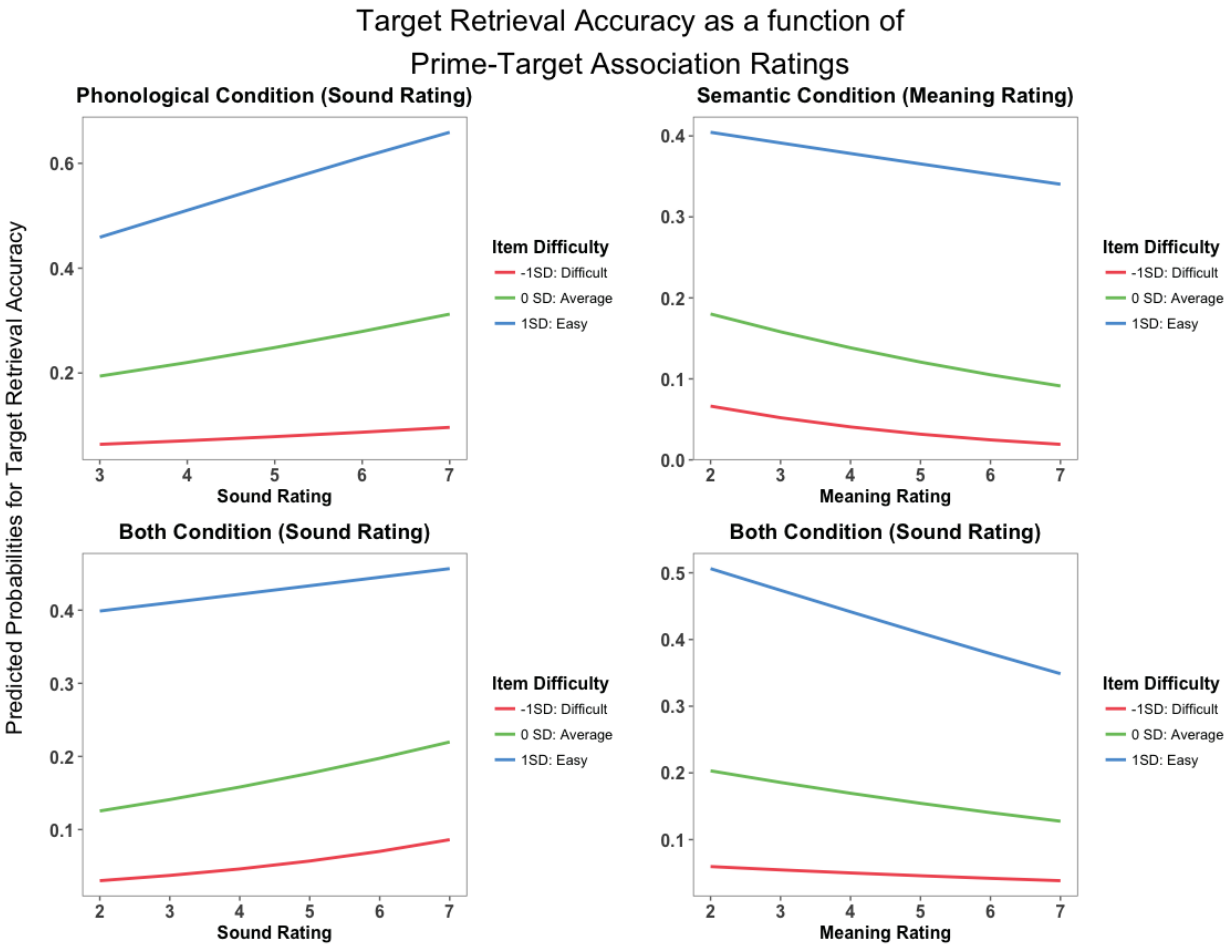

Figure 7. Predicted probabilities of target retrieval accuracy as a function of prime-target association ratings and item difficulty collapsed across Experiments 1, 2 and 3.

Appendix

Complete list of Stimuli

Target	Phonologically Related Prime	Semantically Related Prime	"Both" Prime	Unrelated Prime	Definition
abacus	abscess	slide rule	algorithm	cat	Instrument for performing calculations by sliding beads along rods or grooves
abdicate	abdomen	resign	abandon	pink	To formally renounce a throne
abstain	absolve	refuse	avoid	dove	To refrain deliberately and often with an effort of self-denial from an action or practice
accolade	acclimate	testimonial	applause	wood	A ceremonial embrace; an award or expression of praise
advocate	adverb	condone	advance	plank	To plead the cause of another; to support or promote
Alcott	alchemy	Bronte	Austen	truck	Last name of author of *Little Women*
allocation	allergen	distribution	allotment	screen	Portion set aside for a specific purpose or to particular persons or things
anachronism	anaerobic	misplacement	abnormality	view	Something out of keeping with the time in which it exists

anagram	analytic	puzzle	acronym	chute	Word made by changing the order of letters in another word; e.g. plum, lump
Andes	android	Himalayas	Alps	phone	South America's largest mountain range
auspicious	austere	favorable	advantageous	bottle	Showing or suggesting that future success is likely
banal	banter	ordinary	bland	judge	Obvious or trite; commonplace
Bangkok	banister	Laos	Bangalore	cap	Capital of Thailand
barter	bark	tariff	bargain	light	To trade by exchanging goods for other goods rather than money
Batista	baklava	Franco	Bolivar	plug	Cuban president overthrown by Castro
bewilder	boardwalk	stupefy	befuddle	glass	To cause someone to become perplexed and confused
binomial	biannual	equation	bilateral	youth	A mathematical expression consisting of two terms
Caracas	caravan	Bogota	Cordoba	mint	Capital of Venezuela
carcass	canvas	skeleton	corpse	wine	The complete remains of a dead animal, especially at a butcher's
Carroll	careless	Rowling	Christie	air	Last name of author of *Alice in Wonderland*

Carver	carwash	Edison	Carlisle	lock	Last name of man credited with inventing peanut butter
Casablanca	castle	Rabat	Cairo	banner	Capital of Morocco and famous movie title
chameleon	camelback	gecko	camouflage	bagel	A small lizard with skin that changes color to match its surroundings
Clay	clap	Frazier	Clark	length	Original last name of Muhammad Ali
Clemens	commence	Sawyer	Clayborn	knock	Original last name of Mark Twain
congruent	cognizant	matching	compatible	head	Identical in form; coinciding exactly when superimposed
covenant	convenient	protocol	commitment	freeze	A promise between God and humans
Cummings	cummerbund	Browning	Cunningham	point	20th century American poet whose trademark was using only lowercase letters
Dante	dawn	Homer	Donne	tennis	Italian poet known for writing "The Inferno"
Darfur	darken	Rwanda	Dubai	print	Region in Sudan where guerilla conflict and possibly genocide began in 2003
Dean	deed	Gable	Driscoll	chew	Last name of American actor known for his role in *Rebel Without a Cause*

default	difficult	surrender	disclaim	wrap	To fail to act, to pay, or to appear for judgment in court
deference	decadence	yielding	diffidence	alarm	Humble submission and respect
denigrate	denizen	belittle	demonize	rhino	To criticize unfairly; to attack the reputation of
deplete	depth	consume	delete	egg	To empty of a principal substance; to exhaust the abundance of
diverge	diva	split	differ	llama	To extend in separate directions from a common point; to turn aside or deviate
eccentric	ecstatic	bizarre	erratic	wrestle	Unconventional and slightly strange; deviating from an established or usual pattern or style
elucidate	elusive	clarify	illuminate	noise	To make something clear; explain in detail
embryology	emblematic	neonatology	epidemiology	night	The study of the developing fetus before birth
epithet	epitome	nickname	epitaph	crack	An adjective or phrase expressing a quality regarded as characteristic of the person or thing
facetious	facilitate	sarcastic	frivolous	pawn	Treating serious issues with deliberately inappropriate humor

fervent	forever	intense	feverish	duck	Having or displaying a passionate intensity
foliage	folding	vegetation	forest	kick	A cluster of leaves, buds, or branches
fortuitous	foresee	haphazard	fortunate	lapse	Happening by a lucky chance or by accident rather than by design
Garland	garnish	Ball	Garner	water	Last name of actress who played Dorothy in Wizard of Oz
Gershwin	gestalt	Bernstein	Gerhardt	happy	Last name of American composer most known for Rhapsody in Blue and An American in Paris
gosling	goblin	puppy	gelding	beard	A young goose
Hale	hall	Salomon	Hyde	igloo	Last name of man known for saying "I only regret that I have but one life to give for my country"
Hancock	handle	Jefferson	Hamilton	disc	Last name of first man to sign Declaration of Independence
Helsinki	handkerchief	Oslo	Heinola	shop	Capital of Finland
hemorrhage	homeowner	contusion	hematoma	window	The escape of blood from vessels, including internal and external bleeding

herbaceous	harbinger	blossoming	hibiscus	ill	Term for type of plant without woody or persistent stem, whose leaves and roots are often used for food, medicine, or scent
hoist	hot	dredge	heave	shade	To raise into position by means of a pulley
idiosyncrasy	idiomatic	uniqueness	individualism	finger	A distinctive or peculiar feature or characteristic of an individual, place, or thing
injudicious	injured	thoughtless	iniquitous	key	Showing poor judgment; unwise
instigate	instantiate	provoke	initiate	brush	To goad or push forward; to incite someone to do something, especially something bad
interject	implement	mention	introduce	yellow	To say something abruptly, especially as an aside or interruption
libel	label	perjury	litigate	uncle	The illegal act of writing untrue things about someone
Lindbergh	linoleum	Earhart	Lindell	cash	Last name of first person to fly solo nonstop across Atlantic
loquacious	locket	verbose	literate	candle	Tending to talk much or freely; chatty

Mandela	manila	Gandhi	Mendel	plunge	Last name of South African imprisoned for 27 years before becoming president
meager	meander	sparse	minimal	leash	Lacking desirable qualities, as in richness or strength
Miller	miracle	Albee	Melville	bunch	Last name of the author of *The Crucible*
mince	mice	cleave	mash	king	To cut or chop food into very small pieces
monotony	monogram	invariability	monogamy	jelly	Tedious sameness of tone or sound
Nairobi	narrate	Tripoli	Namibia	bump	Capital of Kenya
nullify	numbing	invalidate	neutralize	plain	Make of no use or value; cancel out
Nuremberg	neurosurgery	Berlin	Norderstedt	image	German city for which anti-Semitic laws were named
obscure	obstruct	esoteric	opaque	lazy	Not readily understood or clearly expressed
obstinate	obstetrician	persistent	opinionated	flute	Stubbornly refusing to change one's opinion or action, despite reason, arguments, or persuasion
omnipotent	omnivorous	unlimited	omniscient	shrimp	Having unlimited power; able to do anything
ostentatious	osteoporosis	flashy	obvious	milk	Characterized by vulgar or conspicuous display

O'Connor	okra	Ginsburg	O'Donnell	train	Last name of first female US Supreme Court justice
ornithology	ornate	herpetology	otolaryngology	bank	Branch of zoology dealing with birds
Oswald	osmosis	Booth	Osborne	cashew	Last name of JFK's assassin
Ottawa	otter	Toronto	Ontario	jump	Capital of Canada
panacea	panda	remedy	placebo	hype	A medicine which can cure any illness
paragon	parachute	ideal	paradigm	runt	A person or thing characterized as a perfect example of a particular quality
polygamy	polygon	marriage	promiscuous	gem	The practice of having more than one spouse at the same time
Prague	prawn	Belgrade	Pilsen	coin	Capital of Czechoslovakia
precocious	precursor	advanced	premature	hunt	Having developed certain abilities or proclivities at an earlier age than usual
pretentious	pretending	gaudy	presumptuous	work	Attempting to impress by affecting greater importance or talent than is actually possessed
prophecy	professor	vision	prognosis	trout	A prediction of what will happen in the future
proposition	propagate	recommendation	presentation	wake	Something offered for consideration or acceptance

Quayle	quake	Mondale	Quinn	lawn	Last name of vice president of George H. W. Bush
recapitulate	recalculate	outline	reiterate	shell	Summarize and state again the main points of something
Revere	reverend	Adams	Reeves	sweat	Last name of American revolutionary known for his midnight ride
Robinson	robbery	Ashe	Robertson	vowel	Last name of first African American Major League Baseball player
Seoul	sofa	Tokyo	Saigon	thigh	Capital of South Korea
Shaw	ship	Wilde	Shelley	cave	Last name of Irish author well known for *Pygmalion* and *Man and Superman*
Sicily	sizzle	Corsica	Sardinia	watch	The largest Mediterranean island; the Italian island known for its archaeological sites and major cities such as Palermo
Skywalker	skyscraper	Kenobi	Solo	volt	Last name of Leia's brother and Darth Vader's son in *Star Wars*
Stockholm	stockbroker	Copenhagen	Strasbourg	cleat	Capital of Sweden
taciturn	tassel	withdrawn	terse	debt	Saying little, reserved, uncommunicative

Thoreau	thorny	Emerson	Tennyson	hum	Last name of American transcendentalist known for *Walden* and *Civil Disobedience*
tic	tip	jerk	twitch	weak	A habitual spastic motion of particular muscles, especially in the face
tsunami	turmeric	hurricane	typhoon	grow	The proper name for a "tidal wave"
Watson	wattage	Doyle	Wilson	ball	Last name of Sherlock Holmes' assistant and friend
Wayne	wake	Kent	Walker	neck	Last name of Batman's secret identity
Yellowstone	yesterday	Glacier	Yosemite	gate	National park in which Old Faithful is located