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Tip-of-the-Tongue States Reveal Age Differences in the Syllable Frequency Effect

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Abstract

Syllable frequency has been shown to facilitate production in some languages but has yielded inconsistent results in English and has never been examined in older adults. Tip-of-the-tongue (TOT) states represent a unique type of production failure where the phonology of a word is unable to be retrieved, suggesting that the frequency of phonological forms, like syllables, may influence the occurrence of TOT states. The current study investigated the role of first-syllable frequency on TOT incidence and resolution in young (aged 18-26), young-old (aged 60-74), and old-old adults (aged 75-89). Data from three published studies were compiled, where TOTs were elicited by presenting definition-like questions and asking participants to respond with "Know", "Don't Know", or "TOT". Young-old and old-old adults, but not young adults, experienced more TOTs for words beginning with low-frequency first syllables relative to high-frequency first syllables. Furthermore, age differences in TOT incidence occurred only for words with low-frequency first syllables. In contrast, when a prime word with the same first syllable as the target was presented during TOT states, all age groups resolved more TOTs for words beginning with low-frequency syllables. These findings support speech production models that allow for bidirectional activation between conceptual, lexical, and phonological forms of words. Furthermore, the age-specific effects of syllable frequency provide insight into the progression of age-linked changes to phonological processes.

Keywords: speech production; tip-of-the-tongue (TOT) states; syllable frequency; aging

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The process of converting an idea into overt speech is much more complicated than it "feels" to the speaker. Even the production of single words involves the transfer of information through at least three stages prior to articulation: conceptual semantics, lexical selection, and phonological encoding (e.g. Dell, 1986; Levelt, Roelofs, & Meyer, 1999; MacKay, 1987). Due to the complexity of these steps, it is logical that words used habitually are produced more efficiently than uncommon or newly-learned items because production processes are more practiced. Indeed, the word frequency effect is one of the most reliable observations reported in the speech production literature, where high-frequency words are produced faster than low-frequency words (e.g. Oldfield & Wingfield, 1965). However, less is known about how the frequency of smaller, sublexical components of words impacts the ease with which words are encoded and produced. The current study examined the role of a specific sublexical measure, syllable frequency, in the post-conceptual stages of production, within the context of two situations where phonological processes are particularly relevant: tip-of-the-tongue (TOT) states and aging.

Syllable frequency refers to the rate of a particular syllable's use within a language. For example, the combined frequency of words containing the syllable /ɪm/ (e.g., the first syllable in the word *impeach*) would constitute its frequency. The overall pattern of these studies has demonstrated facilitation, where words composed of high-frequency syllables are produced faster than words with low-frequency syllables (Cholin, Levelt, & Schiller, 2006; Laganaro & Alario, 2006); Levelt & Wheeldon, 1994; Macizo & Van Petten, 2007). Studies also have shown an advantage specific to first syllable frequency, referring to high-frequency syllables in the onset position (Cholin et al., 2006).

Established models of speech production have different explanations for the syllable frequency effect. One theoretical account has been developed by Levelt and colleagues (Cholin et al., 2006; Levelt, 1989; Levelt & Wheeldon, 1994; Levelt et al., 1999). At the essence of this discrete-stage model is the "*mental syllabary*", a repository of syllable-sized phonological units retrieved by the speaker during phonetic encoding. Having access to premade articulatory programs reduces the resources utilized during motor planning (Aichert & Ziegler, 2004), resulting in rapid and largely errorless speech. Regularly-used syllables are produced using highly overlearned motor sequences, so items in the syllabary serve as encoding shortcuts for a word's articulation (Schiller, Meyer, Baayen, & Levelt, 1996). On the other hand, instead of being retrieved from the syllabary, new or low-frequency syllables are assembled online using smaller phonological segments, yielding slower and more error-prone speech. Importantly, the mental syllabary is accessed only after phonological encoding is completed, when the full phonological form of the word has been assembled. The degree of regular usage that a syllable needs to gain mental syllabary "status" remains to be clearly defined by current models, although it has been hypothesized that the content of the syllabary may differ depending on the language (Levelt et al., 1999). Languages such as English and Dutch contain over 12,000 different syllables, although only 500 syllables are needed to produce 80% of English words and 85% of Dutch words (Schiller et al., 1996), so it would be 'cost-effective' to maintain the few hundred most frequently used syllables in the mental syllabary (Levelt et al., 1999).

An alternative explanation of the syllable frequency effect comes from interactive activation models (e.g. Dell, 1986; 1988; MacKay, 1987), where facilitation from high-frequency syllables occurs from shared activation among lexical candidates that contain the same first syllable. All lemmas with a common first syllable receive partial activation when any of the

words are produced, allowing high-frequency syllables to benefit from their multiple connections with lexical representations in the semantic system and the high concentration of lemmas that converge on a single first syllable. Figure 1 demonstrates the density of connections between lexical- and syllable-level representations for a high-frequency first syllable compared to a low-frequency first syllable. Because high-frequency syllables are repeatedly accessed during speech, the connections between lexical forms and the phonological network are strengthened, both from the top-down activation of the phonological units and the bottom-up feedback activation from the phonological to the lexical level, enabling more efficient spreading of activation during subsequent production of these items. In contrast, low-frequency syllables are used irregularly, causing the strength of the lexical-to-syllable connections to diminish over time. Because of these weakened connections, low-frequency syllables are rendered more vulnerable to phonological retrieval failures.

Empirical support for the syllable frequency effect has largely come from word and pseudoword reading paradigms, although the procedure is limited by the fact that the to-be-named target is provided, confounding the production task with word recognition processes. An alternative way to examine the structures affecting speech production is to isolate the involvement of specific sublexical units when production fails, particularly when the failure is caused by a defect in phonological processing. A TOT state is defined as a temporary inability to retrieve a word, despite a persistent feeling of knowing the intended word (Brown & McNeill, 1966), thought to be caused by a breakdown during phonological encoding (Burke, MacKay, Worthley, & Wade, 1991; Levelt, 1989). Both discrete and interactive activation models agree that although the lexical representation is activated, causing the strong sense of knowing the word, connections to the word's phonological components are weakened, preventing the

phonology of the word from being successfully retrieved. Previous research has demonstrated that TOT states are uniquely influenced by phonological processes, both before and after lexical selection. For example, speakers have fewer TOTs for a target word following pronunciation of words that cumulatively contain the target's phonology (James & Burke, 2000). Speakers are also more likely to resolve a TOT when they encounter phonologically-related words (James & Burke, 2000), specifically one that contains the target's first syllable, as opposed to a later syllable or the target's first phoneme (Abrams, White, & Eitel, 2003).

Because TOTs are influenced by syllabic constraints, syllable frequency might play a role in the incidence of TOT states. Within interactive activation models, high-frequency syllables have more stable connections to the lexical items in the semantic network, making words containing these syllables less likely to result in a TOT state. Once in a TOT state, priming the TOT word's first syllable should promote TOT resolution due to the combination of bottom-up activation from the prime's phonological form and top-down activation from the TOT target's semantic representation, in accordance with interactive activation models. However, in addition to spreading activation to the lexical representation of the TOT target, the phonological prime will also activate other lemmas that possess that first syllable, thereby introducing potential competitors. In that situation, low-frequency syllable targets would have fewer lexical candidates receiving activation from the prime (relative to high-frequency syllables), therefore allowing TOT words with fewer first syllable neighbors to experience more concentrated boosts in activation from the processing of the prime word, and as a result, higher rates of resolution.

In contrast to interactive activation models, discrete-stage models would predict no effect of syllable frequency on TOT states due to the dissociation between phonological and phonetic encoding, where the latter can only begin after the former stage has been completed.

According to Levelt et al. (1999), TOT states represent a phenomenological example of the "rift" between lexical (lemma form) and phonological (word form) representations of words. Given that individuals in a TOT cannot access a selected lemma's phonology, they have not yet completed the phonological encoding processes required to access the mental syllabary and begin the motor planning stage where the syllable frequency effect is said to emerge. Specifically, the pre-constructed syllabic representations stored in the syllabary are purported to be retrieved at a "post-lexical level" (Cholin et al., 2006), while individuals in a TOT state are immobilized at the lemma form level. Thus, the frequency of a word's first syllable should have little influence on TOT states, where the speaker never reaches the level of articulation.

In addition to their significance for models of speech production, TOTs are also particularly salient within the cognitive aging literature due to the increased incidence of TOTs in older adulthood, revealed by subjective reports and diary studies (e.g. Burke et al., 1991; Heine, Ober, & Shenaut, 1999), as well as laboratory studies of experimentally induced TOTs (e.g. Heine et al., 1999; Vitevitch & Sommers, 2003). Compared to younger counterparts, older adults also report less phonological information about the TOT word, indicative of greater deterioration in the connections to phonology (Burke et al., 1991). Older adults' increased incidence of TOTs may be due to age-related weakening in the connections between lexical and phonological representations of words. One theoretical explanation of TOTs, the Transmission Deficit Hypothesis (TDH; Burke et al., 1991; MacKay & Burke, 1990) argues that although the aging process causes a global reduction in connection strength, the isolated nature of lexical-to-phonological representations renders these links particularly susceptible to retrieval failures. Older adults' vulnerability to tasks requiring word-form retrieval suggests that syllable frequency might differentially affect young and older adults' incidence and resolution of TOTs.

Specifically, age differences may become particularly pronounced in words with low-frequency syllables, due to the additive effect of age-related weakening and infrequently-accessed phonological segments. However, such age differences may not be consistent *within* the older adult group. Research from a variety of language measures including TOT resolution (Abrams et al., 2007; Heine et al., 1999; White & Abrams, 2002) and vocabulary (e.g., Lindenberger & Baltes, 1997) suggests that age-related declines in language processing are most pronounced among the oldest adults in their mid-seventies or older. For this reason, the current study has differentiated between two groups of older adults (young-old and old-old) to provide insight into the progression of age-related changes in phonological processing.

Method

Data Collection and Participants. Data were compiled from three published studies conducted at the University of Florida (Abrams & Rodriguez, 2005; Abrams, Trunk, & Merrill, 2007; White & Abrams, 2002)[1].

Across these studies, data from 179 young (aged 18-26), 110 young-old (60-74), and 86 old-old adults (75-89) were used to examine the influence of first-syllable frequency on TOT incidence and resolution. All young adult participants were recruited from psychology courses at the University of Florida and received course credit for participation. Older adults were recruited though the University of Florida Cognition and Aging Laboratory participant pool, a database of community-dwelling volunteers living in Gainesville and surrounding areas. Older adults scored 25 or above on the Mini Mental Status Exam (Folstein, Folstein, & McHugh, 1975) to rule out the possibility of dementia and were compensated at a rate of $8 an hour. Participants were native or fluent English speakers, with normal or corrected-to-normal vision, and no known diagnosis of learning disability or cognitive impairment.

Descriptive statistics for each age group are shown in Table 1. One-way ANOVAs were conducted to compare young, young-old and old-old adults on the following dimensions: education, vocabulary, forward digit span, and backward digit span. Young-old and old-old adults had more education and higher vocabularies than young adults (p <.001), but did not differ from each other (ps > .272). Young adults had a higher forward digit span than old-old adults (p < .003), and a marginally higher forward span than young-old (p < .076), as well as a higher backward digit span than both older groups (ps < .048). Young-old had a marginally higher backward digit span than old-old adults (p <.066), although they did not differ in forward digit span (p >.182).

Materials. Across all studies, a total of 145 words were used as targets in the TOT elicitation task. The CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) was used to find the first-syllable frequency for all stimulus items, defined as the summed frequency of words containing that syllable in the onset position. For example, the onset syllable /kæl/ of *calibrate* occurs in words that have a combined frequency per million of 1543. Words that were monosyllabic, not found in the CELEX database, or elicited no TOT states were excluded, resulting in 130 total TOT targets used for the current study. Among these items, targets falling above the median (974.5) were classified as having "high" first-syllable frequency (N = 65; M = 3746.5, SD = 3593.4) and those falling below the median were considered "low" first-syllable frequency (N = 65, M = 269.8, SD = 279.6)[2]. Out of 10 possible types of syllable structures, the most common syllable structure for both high-frequency and low-frequency syllables was CV (53.8% for high-frequency syllables and 30.8% for low-frequency). Because the current study used existing behavioral data and stimuli sets from previous studies, targets in the high-and low-syllable frequency groups could not be intentionally matched on other lexical dimensions. To

explore whether the two groups of targets differed in other ways, we determined each item's number of phonological neighbors (excluding homophones), positional bigram frequency, length in letters, length in phonemes, number of syllables (all taken from the English Lexicon Project database; Balota et al, 2002), and word frequency (Francis & Kucera, 1982). Descriptive statistics on these dimensions for high- and low-frequency first syllable targets are shown in Table 2, and independent samples t-tests revealed that the only difference besides syllable frequency ($p < .001$) was that high-frequency syllable targets contained more syllables than low-frequency syllable targets ($p < .025$). The two groups were equivalent on all other measures ($ps > .270$).

Procedure. Participants were first provided detailed explanations of a TOT state, describing it as a strong feeling of knowing a word despite an inability to retrieve it. They were then asked definition-based general knowledge questions via computer presentation (e.g., *What do you call a large, colored handkerchief usually worn around the neck?*) and were given the option of responding "Know", "Don't Know", or "TOT". Participants who responded with "TOT or "Don't Know" then saw a list of words and were asked to read each one, and in two of the studies, subsequently made subjective, qualitative judgments about the words, such as difficulty of pronunciation. In the primed condition, one or more[3] of these words was a phonological prime word that shared the same first syllable of the target, while in the unprimed condition none of the words shared any phonology with the target. Then, the question was re-presented, and participants again assessed whether they knew the answer, did not know, or were in a TOT state. After all of the questions had been presented, a multiple-choice recognition test was administered for unresolved questions to ensure that people who reported "TOT" were actually having a TOT

experience for the intended target. A basic flow chart of the procedure is shown in Figure 2, highlighting when the two measures of interest, TOT incidence and resolution, were collected.

Results

Initial "TOT" responses were included in analysis only if the participant subsequently provided the correct answer to the general knowledge question on its second presentation or correctly identified the target word on the recognition test. All ANOVAs were conducted using participants and items as random variables, yielding F_1 and F_2 statistics, respectively. However, in situations where the two analyses failed to produce parallel results, greater credibility was given to the participant analyses due to the items having fewer cases, more data loss, greater variability, and hence less power to detect differences. Furthermore, effect size coefficients (eta-squared) are provided for all focused univariate contrasts.

TOT Incidence. TOT incidence was calculated by dividing the total number of TOTs reported for high- and low-frequency first syllable targets by the number of questions presented in each frequency category.

A 3 (Age Group: young, young-old, and old-old) x 2 (First-Syllable Frequency: high and low) repeated-measures ANOVA was conducted on the mean proportion of initial TOT responses, i.e., TOT incidence. The main effect of age group was significant, F_1 (2, 372) = 6.11, MSE = .011, $p < .002$, F_2 (2, 206) = 7.31, MSE = .002, $p < .001$, as was the main effect of first syllable frequency, F_1 (1, 372) = 18.05, MSE = .003, $p < .001$, F_2 (1, 103) = 6.21, MSE = .008, $p < .014$. However, these main effects were qualified by a significant Age Group x First-Syllable Frequency interaction, which is displayed in Figure 3, F_1 (2, 372) = 8.26, MSE = .003, $p < .001$, F_2 (2, 206) = 5.65, MSE = .002, $p < .004$. To further decompose this interaction, follow-up tests were conducted to examine the effect of syllable frequency separately for each age group. While

both young-old ($p_1 < .045$, $\eta^2 = .01$; $p_2 < .092$, $\eta^2 = .02$) and old-old participants ($p_1 < .001$, $\eta^2 = .06$, $p_2 < .001$, $\eta^2 = .1$) experienced a syllable frequency effect, i.e., more TOTs for low-frequency first syllable words relative to high-frequency, young adults had equivalent rates of TOTs for high- and low-frequency targets ($p_1 > .819$, $\eta^2 = 0$; $p_2 > .605$; $\eta^2 = 0$). Alternatively, for low-frequency target words, the pattern of age differences revealed that old-old adults experienced more TOT states than both young ($p_1 = < .001$, $\eta^2 = .07$; $p_2 < .001$, $\eta^2 = .11$) and young-old ($p_1 < .002$, $\eta^2 = .05$; $p_2 < .001$, $\eta^2 = .18$) adults, who did not differ ($p_1 > .187$, $\eta^2 = .01$; $p_2 > .958$, $\eta^2 = 0$). In contrast, there were no age differences in TOT incidence for high-frequency first syllables ($p_1 > .356$; $p_2 > .154$).

TOT Resolution. To examine the relationship between first-syllable frequency and TOT resolution, an Age Group X First-Syllable Frequency repeated-measures ANOVA was conducted on mean proportion of TOTs resolved following the presentation of a phonological prime. The main effect of age group was significant, F_1 (2, 251) = 4.55, MSE = .16, $p < .011$; F_2 (2, 142) = 1.88, MSE = .06, $p > .156$. Young-old adults had a higher rate of TOT resolution than young ($p_1 < .004$, $\eta^2 = .04$) and old-old adults ($p_1 < .022$, $\eta^2 = .04$), who did not differ ($p_1 > .751$, $\eta^2 = 0$). The effect of first-syllable frequency was also significant, F_1 (1, 251) = 18.0, MSE = .113, $p < .001$, $\eta^2 = .067$; F_2 (1, 71) = 12.98, MSE = .094, $p < .001$, $\eta^2 = .16$, where targets beginning with low-frequency first syllables had higher resolution than targets with high-frequency first syllables. The Age Group X First Syllable Frequency interaction, as shown in Figure 4, was not significant (Fs < 1).

Discussion

The current study produced novel findings suggesting that syllables play a functional role in the occurrence and resolution of TOT states. In particular, the frequency of syllable-level units

becomes most relevant in situations involving weakened connections to phonological forms (i.e., due to aging) or when there is the potential for competition at the lexical level (i.e., due to phonological priming). While cross-linguistic research has shown that syllable frequency facilitates production in languages other than English (Cholin et al., 2006; Laganaro & Alario, 2006; Levelt & Wheeldon, 1994), young adults failed to demonstrate an effect of syllable frequency on TOT incidence, consistent with previous research showing no effect of syllable processing on the production of English words (e.g. Schiller, 1999; 2000; but see Ferrand, Segui, & Humphreys, 1997; Macizo & Van Petten, 2007, for exceptions). However, syllable frequency did facilitate production for older adults, with fewer TOTs occurring for targets containing high-frequency first syllables relative to low-frequency. The fact that older adults alone demonstrated the facilitative influence of syllable frequency suggests that the importance of sublexical frequency in producing language becomes more pronounced with age.

The disparity between young and older adults' sensitivity to syllable frequency in TOT incidence is not entirely surprising given our knowledge about age-related declines in connection strength between semantic and phonological representations of words (e.g., Burke et al., 1991; MacKay & Burke, 1990). This property of cognitive aging coupled with the irregularity with which low-frequency syllables are produced creates an additive effect for older adults and exacerbates phonological retrieval deficits for low-frequency phonological units. This idea is supported by differences in TOT incidence between the older adult groups for words beginning with low-frequency syllables, suggesting that declines in connection strength grow increasingly more pronounced with advancing age, consistent with other language studies showing more pronounced deficits for old-old compared to young-old adults (Abrams et al., 2007; Heine et al., 1999; Lindenberger & Baltes, 1997; White & Abrams, 2002). Further evidence for this

explanation comes from the finding that age differences only occurred for words with low-frequency first syllables. The elimination of an age effect for high-frequency syllables implies that older adults' phonological retrieval problems may reflect a selective difficulty in processing low-frequency sublexical items, contrary to previous suggestions that older adults *consistently* experience higher rates of TOTs (e.g., Burke et al., 1991; Heine et al., 1999; Vitevitch & Sommers, 2003), and that the frequency of the word itself is the critical determinant (e.g., Burke et al., 1991). Here, we have demonstrated that even the oldest adults do not experience increased TOT rates for low-frequency words with high-frequency first syllables.

In contrast to TOT incidence, all age groups demonstrated the reverse (inhibitory) effect of syllable frequency on TOT resolution, where words with low-frequency syllables were more likely to be resolved compared to words with high-frequency first syllables. The opposing influence of syllable frequency on TOT incidence compared to resolution may be caused by lexical competition initiated by the phonological prime word. Once the first syllable of the prime word is activated, there is an automatic spread of activation to the lexical-level representations of other lemmas that share that syllable, thereby forcing the TOT target word to compete with phonologically-similar alternates for production, as shown in Figure 5. Additionally, words with high-frequency first syllables may not only possess a larger first-syllable cohort, but also a cohort containing higher frequency words, exacerbating the competitive effect. Within the context of language perception, syllable frequency has consistently shown an inhibitory effect on recognition processes, where words with high-frequency first syllables are recognized more slowly than words with low-frequency first syllables. However, Perea and Carrieras (1998) qualified this assumption by showing that the inhibitory influence of high-frequency syllables on lexical decision latencies was driven by the frequency of the syllable neighborhood, such that the

slower lexical decision times afforded to words with high-frequency first syllables was due to their greater number of higher frequency syllabic neighbors, as opposed to the sheer volume of the syllable neighborhood. Lexical competition from higher-frequency syllable neighbors may become particularly relevant here, where all the TOT words are low-frequency items, thereby making them highly vulnerable to this competition effect.

As depicted in Figure 5, phonological primes with high-frequency first syllables (such as *desist* for the TOT word *decanter*) activate an extensive array of lexical candidates, thereby increasing the time and effort required for the target to be selected. In this example, many syllable neighbors are likely to be more frequent words than the low-frequency targets due to the large number of lexical candidates, which may further prevent the target from receiving the most activation. In contrast, prime words with low-frequency first syllables (such as *ominous* for *omnivore*) would activate a much more limited subset of candidates, therefore increasing the likelihood that the target will receive the most activation and be selected for production.

In sum, the number of words that share a particular syllable influences production due to the bidirectional spread of activation from the lexical level to the phonological representations of words. When links to syllabic representations are weakened due to aging or infrequent use, having a large syllable cohort is beneficial for production (i.e., less likely to result in a TOT) because all lexical items that contain that syllable receive residual activation when any item with that syllable is produced. On the other hand, when a prime word is processed during a TOT state, the syllable receives activation from an external source, thus leveling the playing field between high-and low-frequency syllables. When activation feeds back up to the lexical level, words with fewer syllable neighbors gain the advantage because activation is distributed among fewer items.

Together, these findings for both TOT incidence and resolution are inconsistent with a "*mental syllabary*" explanation of the syllable frequency effect (Cholin et al., 2006; Levelt, 1989; Levelt & Wheeldon, 1994; Levelt et al., 1999), which states that high-frequency first syllables are produced faster and more accurately than low-frequency first syllables due to the rapid and automatic retrieval of their motor programs. First, given the significant effect of syllable frequency on TOT incidence, syllable frequency (at least for older adults) seems to affect the phonological encoding stage of production, where speakers in a TOT state are unable to retrieve the phonological representations of a selected lexical item. Individuals in a TOT state have not begun the motor planning processes used for successful word production, the stage in Levelt et al.'s model where items are retrieved from the mental syllabary. It is worth noting the possibility that the mental syllabary is utilized only when overt word production is required, which did not occur in the present study. In any case, the current results recommend a role for phonological syllable frequency that emerges at an earlier stage of speech production and can be observed in instances of failed production. Second, if high-frequency syllable words are produced more efficiently than low-frequency syllable words due to the automatic retrieval of the motor programs for high-frequency syllables (versus the online assembly of low-frequency first syllables), then it is unclear why the presentation of a phonological prime would be able to reverse the syllable frequency effect, causing words with low-frequency syllables to be produced more efficiently than words with high-frequency syllables. One potential explanation is that the presentation of a prime word with a high-frequency first syllable causes the syllable's motor program to become temporarily "unavailable" for future production of other words that share the syllable. The same constraint would not apply for producing a word primed with the same low-frequency first syllable because the articulatory programs for these words rely on the assembly of

smaller phonological segments instead of retrieval from the mental syllabary. Thus, high-frequency syllable primes have a greater potential to interfere with the successful retrieval and articulation of the TOT target word.

Beyond these theoretical conclusions, results of the current study offer syllable frequency as a viable measure of phonological relatedness that may be more informative for examining phonological similarity among multisyllabic words compared to other measures, such as neighborhood density, that have largely been studied within the context of monosyllabic or simple disyllabic words. In the current study, 75% of the 130 target words have no phonological neighbors as defined by traditional measures of neighborhood density, making it difficult to use such a metric to examine the influence of phonological similarity on the production of these items. However, it should be noted that the current study did not evaluate the relationship between syllable frequency and phonotactic probability, which measures the probability of phonemes and biphonemes occurring in specific positions within words. More studies investigating the influence of syllable frequency on production are needed to better understand the extent to which the various measures of phonological frequency produce parallel results or capture different components of phonological processing. Disentangling the unique contributions of these various phonological measures may help to shed light on how various types of words and their phonological representations are organized within the lexicon

Future research might also assess whether the syllable frequency effect observed here can contribute to explanations of older adults' most notorious word-finding problems: retrieval of proper names, which becomes increasingly difficult in old age (e.g., Burke, Locantore, Austin, & Chae, 2004). One possibility is that the phonological representations of proper names may contain low-frequency first syllables more often than common nouns, which then exacerbates

older adults' difficulty in retrieving proper names relative to young adults. Further research should also clarify why syllable frequency becomes more critical for production as we age and whether this information can be used to improve phonological retrieval processes in older adults.

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Author Notes

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Footnotes

[1]Only the methodological information relevant for the current study is described. Readers are referred to the published studies for descriptive statistics, detailed demographics, additional procedural and methodological details, and results such as the total numbers of "Know", "Don't Know" and "TOT" responses obtained in each study.

[2]The natural log first syllable frequency for targets classified as having high-frequency first syllables was 7.9 compared to 4.9 for low-frequency first syllable targets, which is comparable to previously-defined cutoffs reported by Macizo and Van Petten (2007).

[3]In two of these studies, the primed condition included only a single phonological prime in the list. However, in the earliest study, White and Abrams (2002), 3 out of 10 words were phonologically-related to the target. Subsequent studies revealed that a single first-syllable prime was sufficient for facilitating resolution of TOTs (Abrams and Rodriguez, 2005).

Table 1

Participant Characteristics for Young, Young-Old, and Old-Old Adults

	Age Group					
	Young		Young-Old		Old-Old	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age*	19.5	1.4	68.4	3.9	79.5	3.4
Education (in years)*	13.6	1.4	16.9	3.2	16.6	2.6
Vocabulary (out of 25)*	15.3	3.0	20.5	3.1	21.0	3.0
Forward Digit Span*	7.5	1.2	7.2	1.3	6.9	1.3
Backward Digit Span*	5.7	1.2	5.4	1.4	5.0	1.2

Note: * indicates significant age group differences, $p < .05$

Table 2

Stimulus Characteristics for High- and Low-Frequency First Syllable TOT Targets

	First Syllable Frequency Category			
	High-Frequency		Low -Frequency	
	M	*SD*	*M*	*SD*
First Syllable Frequency *	3746.5	3593.4	269.8	279.6
Number of Phonological Neighbors	0.7	1.9	0.8	2.1
Positional Bigram Frequency	4383.8	2218.6	3996.4	1712.5
Word Length (in letters)	8.8	2.0	8.6	2.1
Number of Phonemes	7.9	1.8	7.8	2.0
Number of Syllables *	3.5	0.7	3.2	0.7
Word Frequency	2.6	3.0	2.2	5.7

Note: * indicates significant difference between high- and low-frequency syllables, $p < .05$

Figure Captions

Figure 1. Example connections between lexical-level and syllable-level representations within interactive activation models for words with high-frequency and low-frequency syllables.

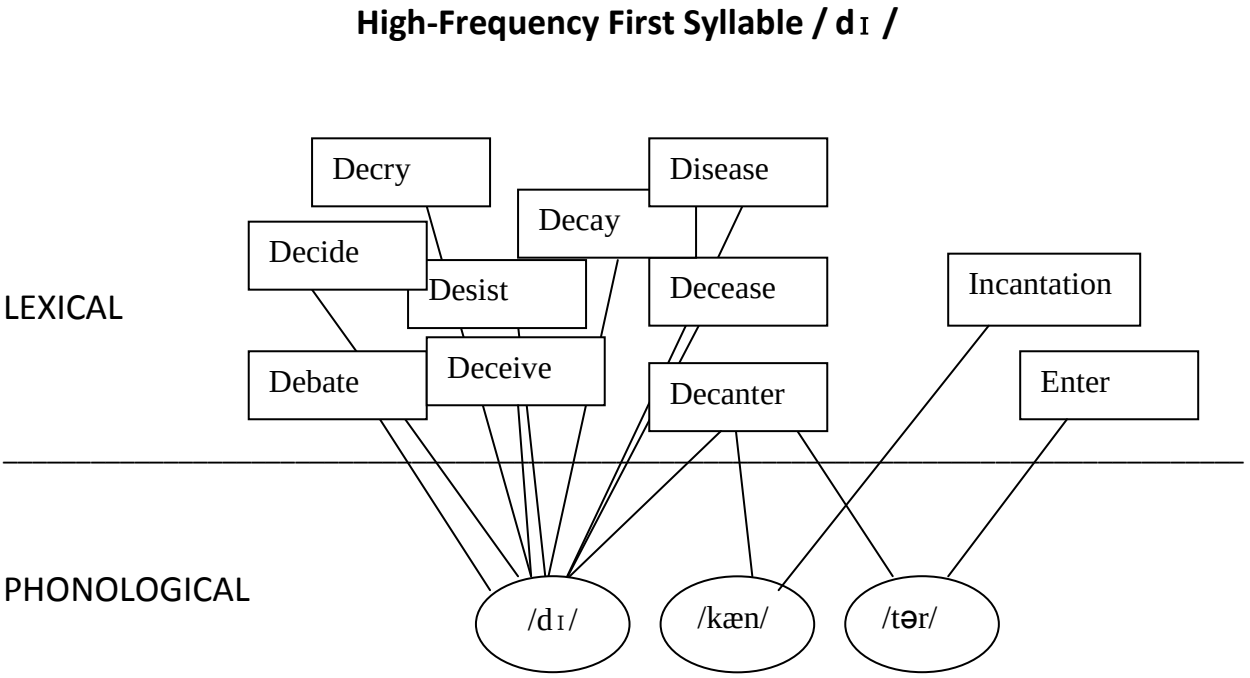
Figure 2. Flowchart of general procedure used across TOT studies, highlighting that TOT incidence is measured after the first presentation of the general knowledge question, while TOT resolution is assessed after the second presentation of the question. In this example, for the TOT target word, *misdemeanor*, the participant would receive the phonologically-related word *misfortune* in the primed condition or the unrelated word *horrible* in the unprimed condition.

Figure 3. Mean TOT incidence (in percent) for targets with low-frequency and high-frequency first syllables for young, young-old, and old-old adults.

Figure 4. Mean TOT resolution (in percent) following phonologically-related primes for targets with low-frequency and high-frequency first syllables for young, young-old, and old-old adults.

Figure 5. Influence of a phonological prime (bolded here for emphasis) with a high- or low-frequency first syllable during TOT resolution. The frequency of words in the syllable neighborhood is represented by the thickness of the lines from the lexical to syllable levels, where dashed lines are for lower-frequency words (weaker connections), and thick lines designate higher-frequency items (stronger connections).

Figure 1



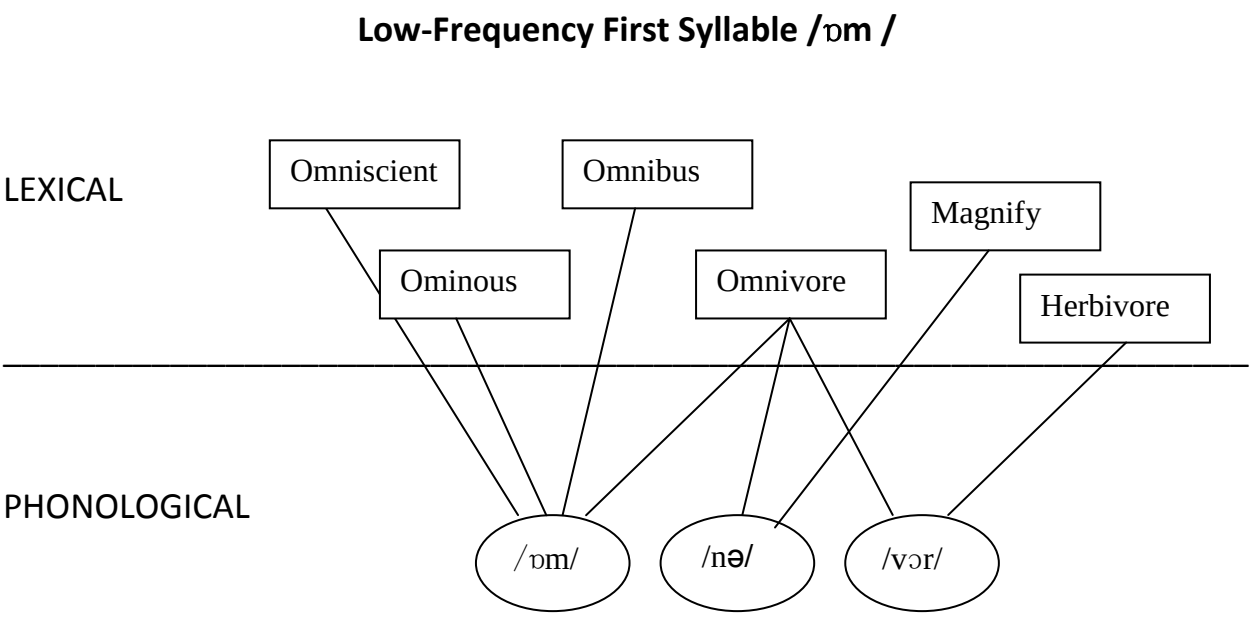


Figure 2

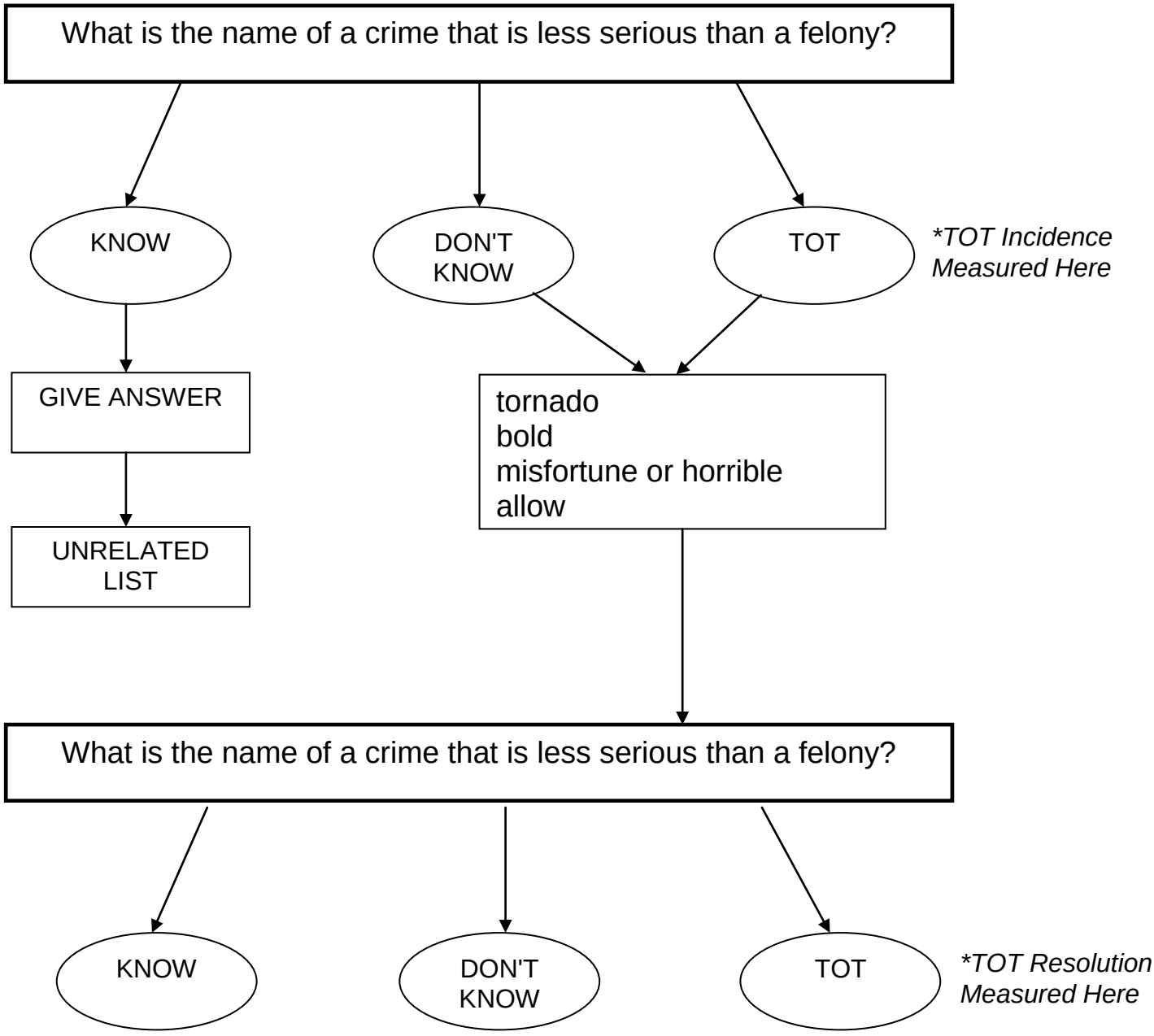

What is the name of a crime that is less serious than a felony?
KNOW
DON'T KNOW
TOT
*TOT Incidence Measured Here
GIVE ANSWER
UNRELATED LIST
tornado
bold
misfortune or horrible
allow
What is the name of a crime that is less serious than a felony?
KNOW
DON'T KNOW
TOT
*TOT Resolution Measured Here

Figure 3

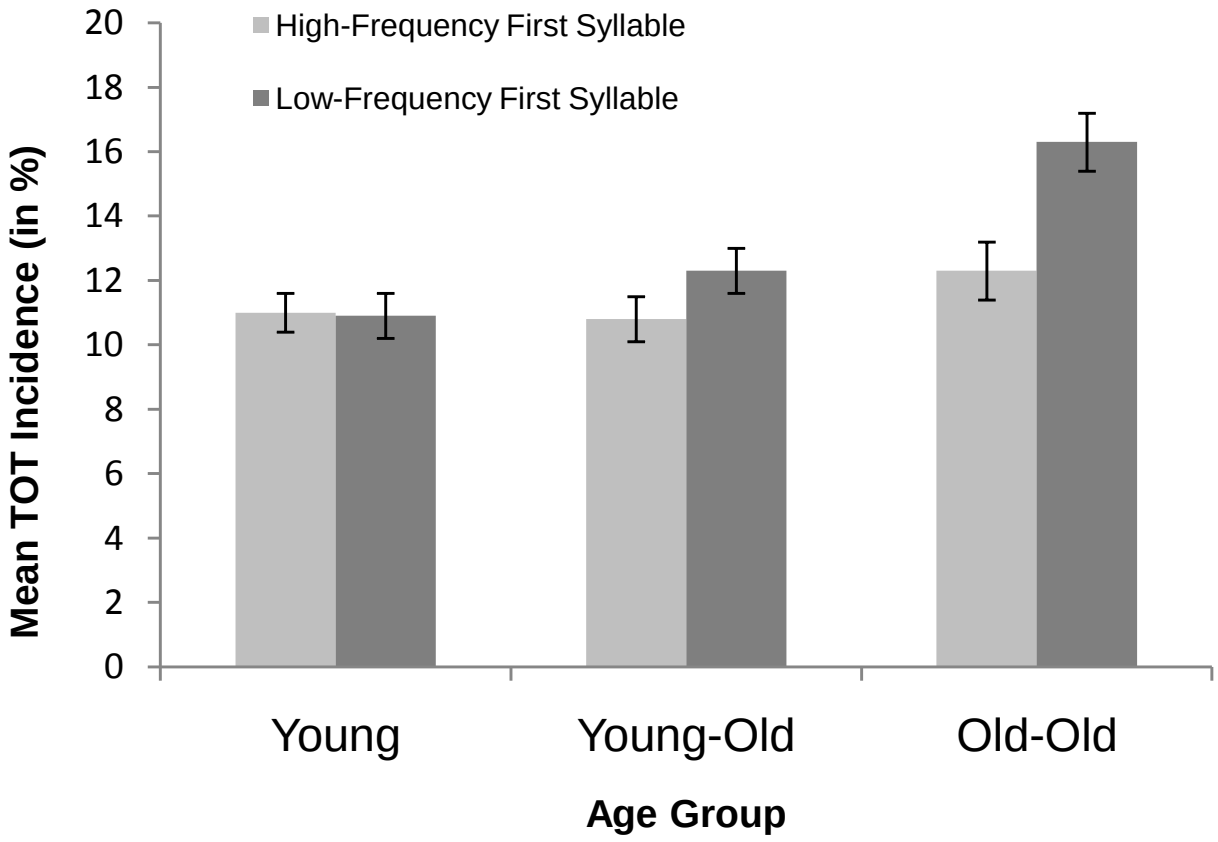

High-Frequency First Syllable
Low-Frequency First Syllable
Mean TOT Incidence (in %)
20
18
16
14
12
10
8
6
4
2
0
Young
Young-Old
Old-Old
Age Group

Figure 4

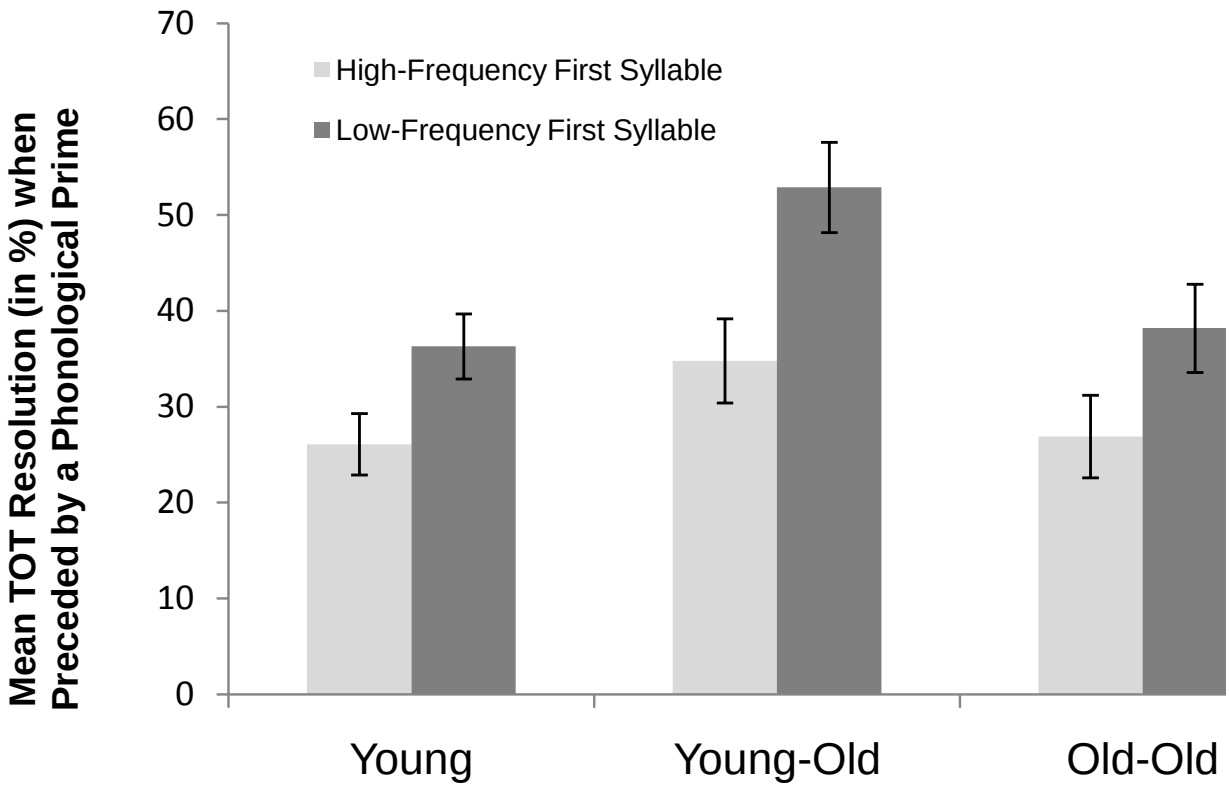
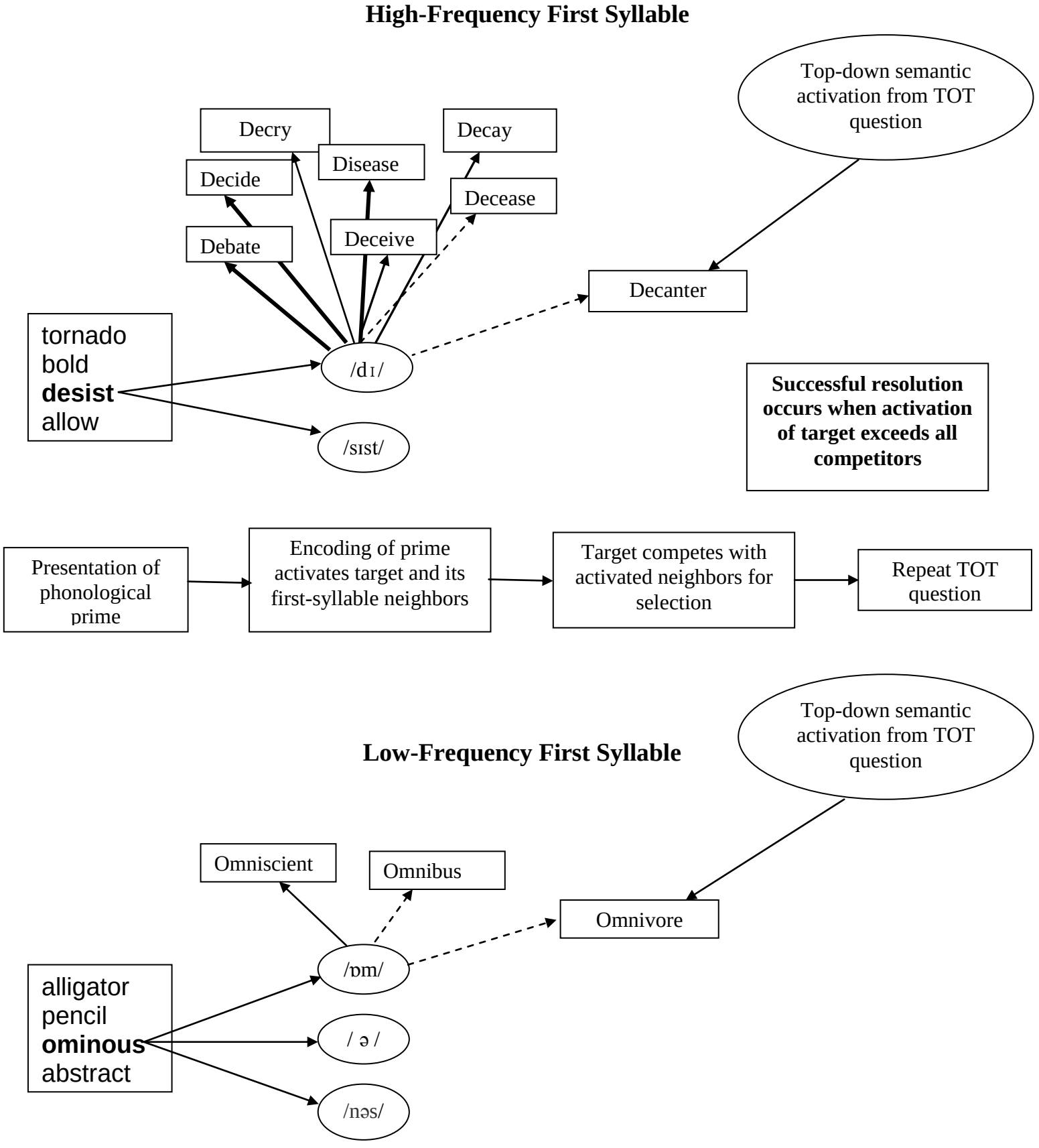

Mean TOT Resolution (in %) when Preceded by a Phonological Prime
70
60
50
40
30
20
10
0
High-Frequency First Syllable
Low-Frequency First Syllable
Young
Young-Old
Old-Old

Figure 5


High-Frequency First Syllable
Top-down semantic activation from TOT question
Decry
Decay
Disease
Decide
Decease
Debate
Deceive
Decanter
tornado
bold
desist
allow
/dɪ/
/sɪst/
Successful resolution occurs when activation of target exceeds all competitors
Presentation of phonological prime
Encoding of prime activates target and its first-syllable neighbors
Target competes with activated neighbors for selection
Repeat TOT question
Low-Frequency First Syllable
Top-down semantic activation from TOT question
Omniscient
Omnibus
Omnivore
alligator
pencil
ominous
abstract
/ɒm/
/ ə /
/nəs/