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Senior Award Winner

Kristine Chang
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Reflective Essay

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Library Undergraduate Research Award Reflective Essay
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My senior thesis in cognitive science, developed over the course of two years, focuses on the tip-of-the-tongue (TOT) phenomenon: that frustrating feeling you get when you know a word but cannot quite remember it. This phenomenon is studied in cognitive psychology experiments as a "window" into language production processes, which usually occur too quickly to study but are slowed down or frozen in TOT states. Ultimately, what began as a plan for a summer research project in my sophomore year has since culminated into a fully fleshed-out senior thesis. Honnold Mudd Library's plethora of resources were critical in helping me to locate a gap in the pre-existing TOT literature by providing dozens of articles that I used to synthesize a novel approach to the topic.

In sophomore year, I developed my understanding of the TOT phenomenon by working as a research assistant in Professor Lise Abrams' cognitive psychology lab, and I soon became curious about how TOTs manifested in languages besides English. In the spring of 2018, I used Honnold Mudd's website to search for TOT research conducted on my heritage language Mandarin, which has highly distinctive linguistic and written properties. Only two articles appeared, with none focused on the Mandarin-specific linguistic aspects of TOTs. After meticulously combing through Honnold Mudd's multiple databases (most notably Psychological Experiments Online, PsycINFO, Academic Search Premier, and Social Sciences Full Text), I confirmed that I had located a hole in the heavily English-focused TOT literature. Not only did this reveal a lack of inclusivity in TOT research, but it seriously constrained the generalizability of past research to other languages.

I was determined to better understand how Mandarin speakers experience TOTs, as well as how the results of a Mandarin TOT study would compare with those of English TOT experiments. With Professor Abrams and a student collaborator, I reviewed studies from Honnold Mudd's databases that used different research methods to elicit TOTs. Together, we developed two experiments to investigate TOT resolution in native Mandarin speakers. That summer, funded by the Summer Undergraduate Research Program (SURP), my collaborator and I tested over a hundred participants in Shanghai and Beijing. I returned to Claremont in the fall, eager to see if our study would support findings in English. Yet as I tried to interpret my data, I soon realized that a straightforward comparative analysis of Mandarin and English TOT studies would not suffice: over decades, past work on TOTs in English has culminated into a mental model of language production which does not account for Mandarin's linguistic structure. In other words, pre-existing frameworks for English TOT studies, which I had originally thought I could apply to my own study, needed to be reconsidered and reimagined for Mandarin.

Daunted but excited by this discovery, I decided to convert my SURP project into my senior thesis and dove into Honnold Mudd's resources for an extensive literature review. I looked through the library's Linguistics and Cognitive Science research guide to find relevant databases and journals, doing a broad search for keywords (i.e., *Mandarin*, *TOT*, *orthography*) to find helpful articles. I quickly learned the importance of using the "right" keywords by trying multiple ones and thinking flexibly about the scope of my search terms. I also looked closely at various cognitive science journals using Honnold Mudd's open access subscriptions, gaining a comprehensive understanding of current literature. Moreover, as I read articles and used them as springboards to find even more papers, I

sometimes found articles that were not available through Honnold Mudd's subscriptions. I was able to use the library's resource sharing program to access relevant papers (e.g. "Syllable Errors from Naturalistic Slips of the Tongue in Mandarin Chinese" by J.Y. Chen, "Memory for proper names: Age differences in retrieval" by Gillian Cohen). As my to-read list grew, I compiled all these articles in Zotero, a free resource endorsed by the library. Through the literature review process, I learned how to critically evaluate articles for relevance and soundness; for example, I initially read several studies on speech errors and natural language processing, but I eventually realized that these were not directly connected with the main themes of my study. In the end, I read over 70 articles spanning 70 years on an array of multidisciplinary topics such as node structure theory, language production, and Mandarin phonology. By synthesizing this information, I eventually proposed a new model for Mandarin language production grounded in literature and extended by data collected from my SURP.

After my literature review, I worked on data analysis and creating my final write-up, and I officially completed my thesis last December. However, I have continued to develop this project in new ways: my collaborator and I virtually presented a poster at the 2020 Psychonomics Conference in November, and we are currently in the final stages of writing an academic paper with Professor Abrams that we will submit to a peer-reviewed cognitive science journal—one that I initially learned about through Honnold Mudd's selection of scientific journals. From this project and from my experience using library resources, I have grown rapidly as a researcher, reader, and thinker. Through analyzing articles, I have practiced how to extract information and meaningfully incorporate it into my own lines of reasoning. Discussing and synthesizing articles with others has also shown me the importance of collaboration, which brings articles to life through conversation. Moreover, I have

grown familiar with the works of researchers who I admire and wish to emulate in my own writing, using their styles and methods as inspiration for my project. Finally, Honnold Mudd's collection of databases and journals has exposed me to the broad history and development of cognitive science, helping me to appreciate the legacy of knowledge that I have inherited from past researchers. The vast collection of accessible information from the library has revealed the community of research that surrounds me, as well as helped me to contribute to it.

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Research Project

The Tip-of-the-Mandarin Tongue: The Effects of Phonology and Orthography on TOT Incidence and Resolution

The Tip-of-the-Mandarin Tongue: The Effects of Phonology and Orthography on TOT Incidence and Resolution

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Author Note

A huge thank you to Professor Lise Abrams for being my SURP and thesis advisor, who has guided me from the present study's inception in 2018 until now. Another big thanks goes to my collaborator PengBo Hu (Pomona College '21) and 莹莹, who helped me navigate the logistics of doing research in China. This study would not have been possible without all of your help.

Abstract

The tip-of-the-tongue (TOT) phenomenon occurs when one knows a word but temporarily cannot recall it. TOT studies in English have demonstrated that providing the first syllable of a word plays an important role in resolving TOTs, and TOTs for English words with higher-frequency first syllables are less likely to be resolved than lower-frequency first syllables. The present study explored TOTs in Mandarin, where words consist of one syllable characters whose visual representation (orthography) is largely independent of their sound (phonology). Participants saw descriptions corresponding to target cheng-yus, four-character Chinese idioms. If they experienced a TOT, they saw a list of words where one was a phonological (Experiment 1) or orthographic (Experiment 2) prime. Phonological primes had a first character different from the target's but contained either its first phoneme or first syllable (homophone), whereas an orthographic prime contained the target's first radical. Primes' first syllables and first radicals were also categorized as higher or lower in frequency. Results showed that a homophone prime marginally increased TOT resolution relative to an unrelated word, whereas a prime with the target's first phoneme or first radical did not. With respect to frequency, TOTs were less likely to occur and were more likely to be resolved for words with higher-frequency first radicals than lower-frequency first radicals, whereas the first syllable's frequency had no effect. These results are interpreted in terms of an interactive activation model for Mandarin where phonological and orthographic systems can both independently and interactively influence TOT resolution.

The Tip-of-the-Mandarin Tongue: The Effects of Phonology and Orthography on TOT Incidence and Resolution

The tip-of-the-tongue (TOT) phenomenon occurs when a word cannot be recalled despite the sensation of knowing the word (Brown & McNeill, 1966). The feeling is often accompanied by partial knowledge of a word's phonological (sound-related) properties, such as its first letter or number of syllables (A. Brown, 1991; R. Brown & McNeill, 1966; Koriat & Lieblich, 1974). Because TOT states are usually unable to be resolved immediately, they act as a "window" into rapid mental processes that are normally difficult to study closely. Thus, researchers since Brown and McNeill (1966) have examined TOT states extensively through questionnaires, diary studies, and experiments. These studies have illuminated that TOTs are not just random occurrences but a phenomenon reliably influenced by several factors. For instance, TOTs occur commonly with low-frequency words and proper names, happen more frequently for older adults than younger adults, and are often accompanied by "persistent alternates", other words related to the unretrievable word (Burke et al., 1991; Cohen & Faulkner, 1986; Jones, 1989).

More importantly, the universality of TOTs allows for the study of fundamental underlying mental processes such as word retrieval and speech production (Ecke, 1996; Gollan & Silverberg, 2001; Ouyang et al., 2020; Pureza et al., 2013; Shin, 2019; Thompson et al., 2005; Vigliocco et al., 1997). TOTs occur in various languages across the world for both monolingual and multilingual speakers. Schwartz (1999) conducted a survey of speakers of 51 languages and found that roughly 90% of the languages had a phrase for the TOT experience which—like English—uses the words "tongue" or "mouth." Even speakers of languages that do not have a term for TOTs, such as the Mayan language Q'eqchi', still recognize the experience when described to them (Brennen et al., 2007). TOTs are also not limited to verbal languages; speakers

of signed languages have similar experiences where one cannot fully remember a sign, known as the "tip of the finger phenomenon" (Shin, 2019; Thompson et al., 2005). Just as with spoken languages, speakers of signed languages can often recall the first letter (i.e., finger-spelled handshape) of a word, pointing to similar underlying causes of TOTs regardless of different modes of language production (Thompson et al., 2005).

Despite their universality, TOTs occur in language-specific ways which may illuminate key differences in how speakers mentally represent languages. These differences are especially important as much of TOT theory is grounded in studies conducted in English, resulting in models of language production limited by the language's particular structure. By studying TOTs in a variety of languages, researchers can create a more holistic and complete picture of how TOT states work. For instance, Italian speakers are able to recall the gender of a word that they cannot fully retrieve, suggesting that grammatical gender—and other syntactic properties—need to be further developed in current models of language production (Caramazza & Miozzo, 1997; Vigliocco et al., 1997). Additionally, signers of American Sign Language (Thompson et al., 2005) and Korean Sign Language (Shin, 2019) can often recall the handshape, location, orientation, and—to a lesser extent—the movement of a sign, which challenges language production theory to account for the retrieval of muscle-movement-related aspects of a word. Ultimately, the study of TOTs can shed light on the mental processes that remain universal or differ across languages, contributing to the creation of more nuanced and inclusive models of language production.

Causes of TOTs

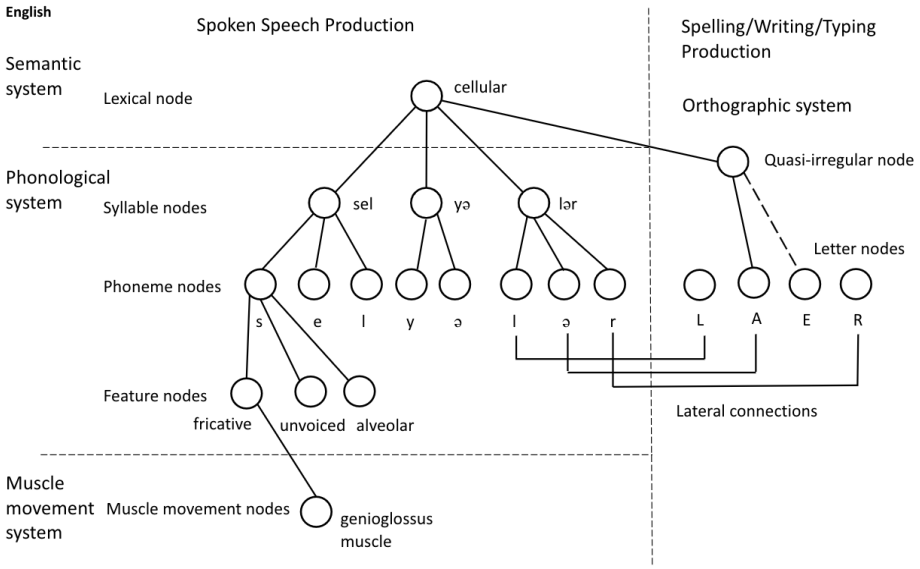
Although debate exists regarding the exact cause of TOTs, this paper utilizes the two dominant, related theories that have emerged in the TOT literature based on English speakers:

node structure theory (NST) and its correlate, the *transmission deficit* (TD) *hypothesis* (MacKay & Burke, 1990; see Brown & McNeill, 1966 for the related but less precisely specified *partial activation hypothesis*). While NST lays out a working mental model of language production, the TD model explains how TOTs arise within this model. The paper also notes the competing related theories of the *interactive activation network* (Stemberger, Elman, & Haden, 1985) and the *blocking hypothesis* (Jones, 1989; Woodworth, 1929), which it will briefly cover.

NST postulates an interconnected mental network of hypothetical representations called nodes, where each represents a unit of information such as a word or a syllable. Nodes are hierarchically organized into semantic (meaning-based), syntactic (grammar-based), orthographic (writing-based), and phonological (sound-based) systems that interact with one another. Figure 1 shows how nodes for the word *cellular* can be represented (MacKay & Abrams, 1998; MacKay & Burke, 1990). In this example, the lexical (word-based) node "cellular" sits at the highest level of the network. Within the spoken speech production system (left half of Figure 1), this node connects underneath to smaller pieces of information represented by other nodes such as syllables and individual sounds called phonemes. Eventually muscle movement nodes are reached so that the word can be physically articulated.

Figure 1

Node structure representation of 'cellular', adapted from McKay and Abrams (1998)



Note. All connections are bidirectional; solid lines represent excitatory connections, while dashed lines show inhibitory connections. Most feature and muscle movement nodes are not shown.

Retrieval of the information contained in a node is determined by two processes, node priming and node activation. Within NST, each node connects with several other related nodes to form a network. Nodes that are active or being used can pass on subthreshold excitation to connected nodes, a process called node priming. Priming can be either inhibitory or excitatory, but regardless it is spread simultaneously across many nodes at once. When a node receives sufficient excitatory priming to cross a specific threshold, it is activated—that is, its content is able to be retrieved—and will subsequently prime other connected nodes (Abrams, White, & Eitel, 2003). Specifically, when a node from a higher level activates a node at a lower level, this process is called "top-down activation;" on the other hand, when nodes from lower levels activate a higher node, this is "bottom-up activation." Note that there are key differences between a node being primed and a node being activated. Multiple nodes can be primed during the process of word retrieval, but only the node with the most and sufficient priming will be

activated in the end, which is necessary for retrieval to occur (MacKay & Burke, 1990). Also unlike priming, activation of nodes occurs in sequence. NST posits that language production occurs in order, so that one must activate the first phonological node of a word before the second node, and so forth (MacKay, 1987). In successful speech production of a left-to-right language, lexical nodes must activate all phonological nodes of a word properly from left to right, which then activate muscle movements to physically produce the word.

Based on NST, the TD model posits that TOT states are a phonological phenomenon, which occur when a lexical node representing a word is activated but only weakly primes its phonological nodes (Burke et al. 1991; James & Burke, 2000; MacKay & Burke, 1990; Rastle & Burke, 1996). During TOT states the lexical node at the highest level is activated through semantic information, but that lexical node sends weak top-down activation to lower nodes, which results in a failure to activate and retrieve the necessary phonological information. This weakening between bidirectionally connected nodes may occur due to infrequent or non-recent use of the word or due to other factors such as aging. For example, the lexical node for *spelunker* may not have been activated recently, so its connections to its phonological nodes /spɪ/, /lʌŋ/, and /kər/ may have weakened. As a consequence, some or none of the phonological nodes are retrieved, and a TOT state results. When some of the nodes are activated, the person in the TOT state might recall the first phoneme of a word but not the word in its entirety. The person might also recall other related words, as the lexical node or some of the phonological nodes of the correct word may activate other lexical nodes.

An alternative view for how TOTs occur is the blocking hypothesis first proposed by Woodworth (1929), which assumes that related words or sounds block the retrieval of the correct word. This is possible under the interaction activation network model proposed by Stemberger et

al. (1985). While NST assumes that the word with the greatest amount of priming is activated, the interactive activation network model further posits that activated nodes prime other nodes at different hierarchical levels but suppress competing nodes at the same level. Jones (1989) terms these related same-level words and sounds as *interlopers*, arguing that they inhibit the retrieval of the desired nodes in TOT states. When phonological nodes of an interloper are primed, the correct phonological nodes are inhibited and unable to be retrieved, creating a TOT state. To test this theory, Jones (1989) presented participants with general knowledge questions to induce TOT states, as well as an interloper which either preceded or was presented after the question. Interlopers fell into four categories: phonologically and semantically related (*abnormality* for the target *anachronism*), only phonologically related (*baulk* for *braise*), only semantically related (*incubus* for *banshee*), or not related (*fossilize* for *hospice*). Participants were asked to report whether they were in a TOT state after each question and interloper, along with whether they could remember initial sounds or the number of syllables of the correct word, i.e. the target word. In support of the blocking hypothesis, the study found that more TOT states occurred when phonologically related interlopers were presented relative to unrelated words. Additionally, more TOT states occurred when interlopers were presented at the time of retrieval rather than beforehand, suggesting that the closer the interloper was presented to the time of recall, the more it hindered word retrieval. Jones (1989) was later replicated by Maylor (1990) with older adults with similar results.

However, Jones (1989)'s results were not conclusive, as the study did not report the number of correct and incorrect retrievals that participants made. If phonological interlopers actually interfered with retrieval, then they should create more TOT states *and* activate incorrect answers to the questions by blocking related phonological nodes. On the other hand, if the

interlopers had actually facilitated retrieval, participants should resolve TOT states more frequently and provide the correct answers to the questions more often. However, the study did not provide such information about participants' responses. Additionally, the study did not check whether participants were in a TOT state for the correct target word. This is necessary to ensure that interlopers were having their intended effect instead of acting on a completely different word that the participant believed was the correct target word. Even though participants were asked to give the first letters of the target word and often did so successfully, this result may have occurred because half of all interlopers shared the same first letter as the answer to the question. Thus participants may have noticed relationships between the target words and the interlopers, using the interlopers to guess the correct initial parts of the word. Perfect and Hanley (1992) modified Jones (1989)'s experiment such that it included a control group who were not presented with interlopers. The study found that even when the control group did not see interlopers, they had more TOTs in response to the questions originally paired with phonologically related interlopers in Jones (1989), which calls into question the objectivity of the original stimuli. Meyer and Bock (199) also used a similar experimental paradigm as Jones (1989), finding that related interlopers—especially if they were phonologically related—actually *helped* with correct word retrieval relative to unrelated interlopers, regardless of whether the interlopers were shown after the general knowledge question or an initial attempt at retrieval. Ultimately, the blocking hypothesis seems an unreliable explanation for how TOT states arise.

Meanwhile, the TD model posits that interlopers are not the cause but rather by-products of the TOT phenomenon. Because the TD model posits that TOT states occur from weakened connections to phonological nodes, the model predicts that giving phonological cues—such as a phoneme or syllable of a word—actually facilitates retrieval during TOT states. These cues

would act as *primes*; in other words, providing these cues would prime the connection between the lexical and phonological nodes by providing an extra boost for a phonological node that cannot be retrieved at the moment. This prediction is in line with Meyer and Bock (1992) who demonstrated that related words facilitate TOT resolution. It was also shown by James and Burke (2000) who induced TOT states in participants by presenting them with general knowledge questions one-at-a-time whose target words were low-frequency words. Participants were asked to type in the correct answer or indicate whether they were in a TOT state after each question. They then said a list of 10 words aloud which sometimes contained five words sharing one or more phonemes with the intended target word. For example, if stuck in a TOT state on the target word *gourmet*, participants saw a list that included ***g****ravity*, *d****ur****ation*, *ea****r****thly*, *calu****m****et*, and *gains****ay***. After reading the list aloud, participants were presented with the same question that induced a TOT and asked to answer it again. Just as predicted by the TD model, processing phonologically related words increased rates of correct TOT resolution relative to a list of unrelated words.

Further research has shown that the first syllable of a target word is a particularly important phonological prime in TOT resolution. Within the TD model, the first part of the word plays an essential role in word retrieval, as the first part of a word must be stimulated in order for a word to undergo full left-to-right activation. Abrams et al. (2003) investigated which parts of a word facilitate TOT resolution by using a similar experimental paradigm as James and Burke (2000), in which general knowledge questions were presented to induce TOT states in participants. After each question, participants indicated aloud whether they knew a word, did not know a word, or were in a TOT state. They then read a list of words which included phonological primes that contained the same first letter (Experiment 1), the first, middle, or last

syllable (Experiment 2), or the first phoneme or first syllable of the target word (Experiment 3). If the participants did not know a word or were in a TOT state, they verbally re-attempted to answer the initial question. The three experiments showed that of all the primes used, only providing the first syllable facilitated TOT retrieval relative to an unrelated word. Abrams et al. (2003) explained the ineffectiveness of the initial phoneme in that providing the initial phoneme of a target word may prime too many first-syllable nodes that begin with the same phoneme. However, providing the first syllable primes a fewer number of nodes that contain that particular syllable, resulting in a greater accumulation of priming—and thus higher chance of activation—for the correct lexical node (see Figure 2). Moreover, the priming result was specific to TOTs and did not occur for questions to which participants responded "don't know." According to the TD model, priming would strengthen pre-existing connections between nodes; participants cannot experience a priming effect for a word they do not know, as the lexical node for the word would not exist. Thus this TOT-specific effect provides further evidence for the TD model as well as reassurance that participants are able to correctly identify TOT states during experiments.

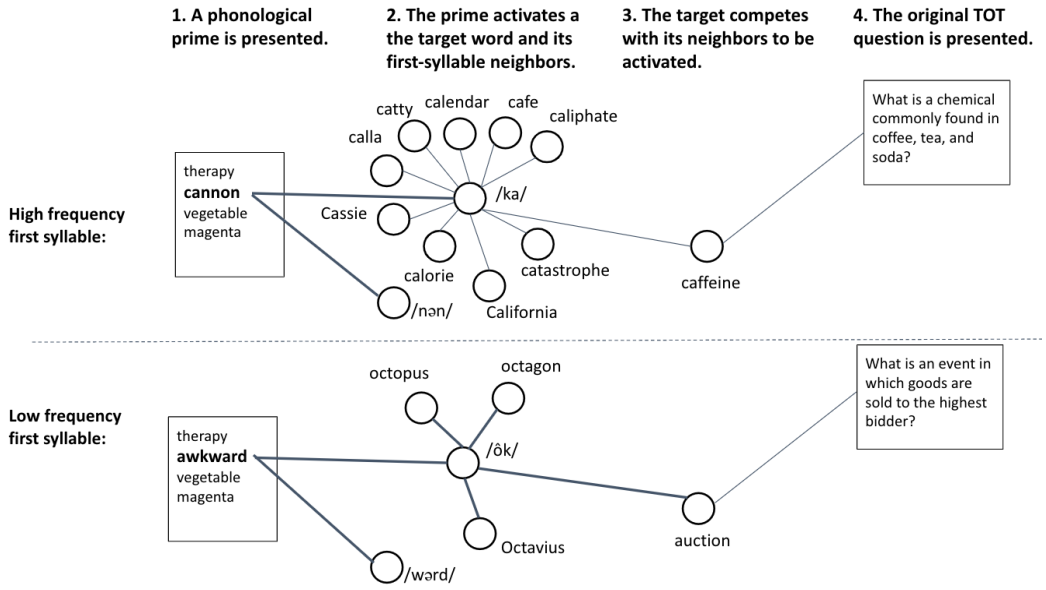
Studies in other alphabetic languages have also investigated the importance of the first syllable in TOT retrieval. Similarly to TOT studies conducted in English, Hofferberth-Sauer and Abrams (2014) found that the first syllable created a facilitatory effect for TOT resolution in German. The study induced TOTs in German speakers by presenting general knowledge questions and asked them to type down their answers in order to measure their response times. Upon entering a TOT state, participants were presented with the correct first syllable of the target word, an incorrect syllable with the same frequency as the correct syllable, or a control condition that showed a row of Xs ("xxx"). As expected from Abrams et al. (2003), participants given the

correct first syllable resolved TOT states more often relative to an incorrect syllable or a control condition. Moreover, when presented with the correct first syllable, participants resolved TOT states approximately twice as fast relative to the control. The faster reaction time can be explained by the TD model, as presenting a participant with the first syllable immediately gives an artificial "boost" of priming to the target word so that it is more readily retrievable. However, for a participant in the control state, there is no concentrated priming from a given first syllable word, so the correct TOT word would be retrieved more naturally and slowly.

Other studies have investigated whether the first syllable priming effect is modulated by syllable frequency, the rate at which a particular syllable occurs in a certain language. For instance, the frequency of the syllable /nI/ is based on how often it is used in English, whether it occurs in the word *kneecap* or *tiny*. If a syllable occurs frequently, it is likely that the syllable occurs in several words so that its phonological node connects to many other nodes. In other words, a high-frequency syllable has a greater *neighborhood density*, the number of lexical nodes that connect to a syllable node. Neighborhood density explains why English speakers in TOT states who are primed with the first syllable of the word resolved fewer TOTs when that syllable had a high frequency rather than a low frequency (Farrell & Abrams, 2011). A high-frequency first-syllable node often has a greater neighborhood density (e.g., is connected to a greater set of lexical nodes). Therefore, when the high frequency syllable node is activated, each connected lexical node receives a relatively small amount of priming compared to when a low-frequency first syllable is activated (see Figure 2). Moreover, there may be words that are higher in frequency than the target, so the transmission of priming to those words may be faster than to the target. Thus the full target word is less likely to be retrieved.

Figure 2

First syllable priming effect for higher or lower frequency first syllables



Note. The thickness of the lines indicates the amount of priming between connections. There are more nodes connected to high-frequency syllables, causing priming to be distributed weakly amongst many nodes. Additionally, words such as *café* or *calendar* might be higher frequency than *cannon* and therefore have stronger links that facilitate retrieval.

In contrast to TOT resolution, first syllable frequency can influence TOT incidence in an opposite fashion, where words with low-frequency syllables can result in more TOTs. Farrell and Abrams (2011) found that young adults did not experience any first syllable frequency effect for TOT incidence but that older adults experienced more TOT states when retrieving words that began with relatively low-frequency first syllables compared to words with high-frequency first syllables. Older adults in general experience more TOT states, as connections between phonological and lexical nodes weaken due to aging (Burke et al., 1991; Heine et al., 1999; Vitevitch & Sommers, 2003). These compromised node connections are further exacerbated by low frequency syllables, which are used less often and therefore have weak connections with

other nodes. Thus, the combination of aging and low-frequency first syllables increases rates of failed word retrieval. However, as this study was only conducted in English, whether first syllable frequency plays a role in TOT incidence for speakers of other languages remains to be determined.

Pureza, Soares, and Comesaña (2013) raised the question of whether syllable frequency plays into the first syllable priming effect found in previous TOT experiments. The study examined how first and last syllable primes affected TOT states in speakers of European Portuguese, a language with more well-defined syllable boundaries than English or German. The study elicited TOT states in European Portuguese speakers through a picture naming task in which participants named images showing objects with two-syllable, three-syllable, and four-syllable names. After attempting to name an image, participants saw a list of 14 words that included four pseudowords with the phonologically related first syllables, phonologically related last syllables, or no similar syllable of the target word. For example, if a picture represented the target word *pincel* (paintbrush), the pseudowords for the first syllable condition would include *pintro*, *pimpota*, *pintri*, and *pimbrano*. Participants then attempted to resolve the TOT state. Results showed that four-syllable words produced the most TOT incidence, as predicted by the TD model where more nodes would need to be activated in order for the entire word to be retrieved. Unlike studies in English, this study found that both the first and last syllable primes created higher rates of TOT resolution than the control group. While the first and last syllable primes did not differ significantly in their facilitatory effects in an initial analysis, the last syllable primes showed the highest percentage of TOT resolution in an *a posteriori* analysis that controlled for target words' syllable frequency and neighborhood density. Thus, the study recommended that first syllable frequency in previous TOT studies must be taken into account,

in order to see whether the first syllable effect might be influenced by syllable frequency. For example, if the first syllables of target words used in an experiment have lower frequencies than the words' second or third syllables, priming first syllables would activate a fewer number of competitors and lead to more TOT resolution. If syllable frequency is not taken into account, it would then appear that first syllables create a stronger priming effect than the second or third syllables solely because of syllable position. Furthermore, the study demonstrated that the last syllable is able to prime target words along with the first syllable, raising the question of whether syllables can play different roles in different languages. In European Portuguese, it may be that syllables towards the end of the word are more salient and easier to recall, as many words stress the penultimate and last syllables. Or, because Romance languages tend to have predictable end syllables, participants may have been able to strategically use last-syllable primes to retrieve target words. Nonetheless, further studies are needed to more closely examine how syllable priming and syllable frequency work in TOT states for speakers of various languages.

Mandarin TOT studies

The linguistic structure of Mandarin has key differences from English that make Mandarin a language of great interest for studying TOTs. English is an alphabetic language that uses 26 letters, each of which corresponds with one or more phonemes. The letters combine to "spell out" words and sentences, so that a reader can generally tell how a word sounds based on its letters. Importantly, English phonology usually overlaps with orthography—the way a word is written. There are some exceptions such as homophones (e.g., *bare*, *bear; plane, plain*) in which different spellings (orthography) are pronounced identically (same phonology). As opposed to English, Mandarin is a morphosyllabic language consisting of one-syllable characters that typically each map onto a distinct morpheme—an individual unit of meaning. Characters are

combined, usually in pairs or triplets, to form new morphemes. Each character has one of four tones, different pitches which help to determine the character's meaning. For example, the two-syllable word 电脑 *dian4nao3* ("computer") is composed of the one-syllable characters 电 *dian4* ("electricity") and 脑 *nao3* ("brain"), with tones indicated by the Arabic numerals. Unlike English, phonology and orthography are opaque in Mandarin in that characters usually do not indicate their pronunciation. Instead, Mandarin speakers must memorize how each character sounds. While previous TOT research done in alphabetic languages claims to prime phonology, it also primed orthography due to the writing systems used in the studies. However, the linguistic structure of Mandarin allows for the study of how phonology, independently of orthography, influences TOT incidence and resolution.

Existing literature regarding the TOT phenomenon in Mandarin speakers is sparse and has focused on the effect of non-linguistic factors, such as semantic distraction, bilingualism, and aging (Chen et al., 2013; Peng & Mao, 2018). In a study on the TOT phenomenon and aging, Peng and Mao (2018) found that older people's deficits in "access and deletion functions" may lead to more TOT incidence in Mandarin speakers. In two experiments, researchers presented an interferential word that was semantically connected to the target word either before or while participants were prompted to retrieve the target word. They found that with and without interferential words, older participants were more likely to have TOTs than younger participants. The study suggested that aging reduces the ability to access relevant information because of activation of irrelevant information, as well as the ability to delete irrelevant information when it is no longer useful. Thus, older people retrieve information less efficiently and are more prone to TOT states. Meanwhile, Chen et al. (2013) investigated the TOT phenomenon in bilingual speakers who speak both Mandarin and Cantonese. They found that the more frequently a

bilingual used a language in daily life, the fewer TOTs they had in that language. This result provides support for NST, as the more frequently used a word is, the stronger its connections to other nodes and therefore the less likely a TOT state will occur with the word.

Only one study to date has examined how Mandarin phonology plays a role in TOT states. Using pictures of celebrities to elicit the retrieval of their names, Ouyang et al. (2020) investigated how aging, semantics, and phonology interact in Mandarin speakers during TOT incidence. Notably in the study's second experiment, before participants saw target pictures, they were shown other celebrities' names that acted as primes belonging to one of six categories: (1) semantically related (sharing the same occupation of the target celebrity) and sharing the first character of the target celebrity's name; (2) semantically related and sharing the same first syllable but not same character of the target celebrity's name; (3) semantically related but not phonologically related; (4) semantically unrelated (having a different occupation than the target celebrity) and sharing the first character as the target celebrity's name; (5) semantically unrelated and sharing the same first syllable as the target celebrity's name; and (6) semantically and phonologically unrelated. Older and younger participants both benefited from simultaneously phonologically and semantically related primes (conditions 1 and 2 above) in decreasing TOT occurrence, although older participants experienced a larger priming effect. Additionally, older participants benefited from fewer TOT incidences when the primes shared the same character than just the same syllable, whereas younger participants benefited equally from both. These results suggest that TOT states in Mandarin may be influenced by first syllable primes as in English and that orthography, which has not been studied in TOT studies in alphabetic languages, may affect TOT states.

However, there is no literature up to this date that exclusively focuses on how the unique linguistic characteristics of Mandarin, i.e., Mandarin phonology and orthography, influence TOT incidence and resolution. Unlike factors like aging, the linguistic characteristics of Mandarin concern the language itself—how Mandarin is pronounced and written, and how these two aspects are connected. Ouyang et al. (2020)'s study does examine how phonological priming can affect TOT incidence, but the study only found a priming effect for primes that were both semantically and phonologically related to the target word, and one therefore cannot conclude that purely phonological cues have an effect on TOT states. Additionally, the study used the first characters of celebrities' names as primes. The first character of a Mandarin name acts as that person's last name, and there are a limited number of characters that are able to serve as last names. Thus, the primes belong to a small subset of Mandarin characters and may not be representative of all Mandarin characters. Moreover, the study ultimately focused on aging rather than on phonology or the first-syllable effect. The study did not consider whether phonological priming affects retrieval of non-proper-nouns, how first syllable frequency may have affected their results, how orthography separated from phonology can influence TOT states, or how the characteristics of the Mandarin syllable such as its simple structure and its unique connections with morphemes may play a role in TOTs. As discussed previously, it has been well established in English and other alphabetic languages that the rate of TOT incidence and resolution is mediated by the frequency of phonological units, and these units can also help participants to resolve TOTs. Whether these general findings can be replicated, extended, or modified in Mandarin speakers is of theoretical interest, as the linguistic features of Mandarin offer new opportunities to explore certain aspects of the TOT phenomenon in further detail.

Mandarin phonology

Mandarin has other phonological traits different from English and other alphabetic languages that may affect how language production works. Specifically, the Mandarin syllable plays a different role and has unique characteristics from the English syllable, which has previously been shown to play an important role in TOT resolution in English speakers. The present paper distinguishes between the Mandarin syllable and the Mandarin character in that the syllable is a purely phonological unit separate from how it is written. For example, the character representing electricity is 电, but the syllable associated with this character is *dian.*

English uses over 12,000 distinct syllables (Farrell & Abrams, 2011) which can include complex consonant clusters on either side of a vowel. Unless a word is monosyllabic, syllables typically do not have individual meanings—for instance, the word "computer" consists of the syllables /kəm/, /pju/, and /tɚ/, which usually cannot stand alone as words. Additionally, English syllables frequently undergo resyllabification (Chen et al., 2002), in which phonemes of a word or phrase are divided into new syllables. For example, the phrase "my bike is" can be re-syllabified as "mai.bai.kis" when speaking (Vroomen & de Gelder, 1999), in which the /k/ sound originally from "bike" forms one syllable with the word "is." However, Mandarin syllables each map onto a distinct morpheme with little resyllabification (Chen et al., 2002). Their makeup is relatively simple, as Mandarin has fewer phonemes overall than English, and the Mandarin syllable only allows up to one phoneme on either side of a vowel. Because of these constraints, there are only about 400 Mandarin syllables, with 1200 syllables if tone is taken into account (Chen et al., 2002). Thus, Mandarin abounds with homophones; the average Mandarin syllable corresponds to four distinct morphemes, with some syllables representing up to 40 morphemes (Zhou & Marslen-Wilson, 1995). For example, the syllable *dian4* can, among many

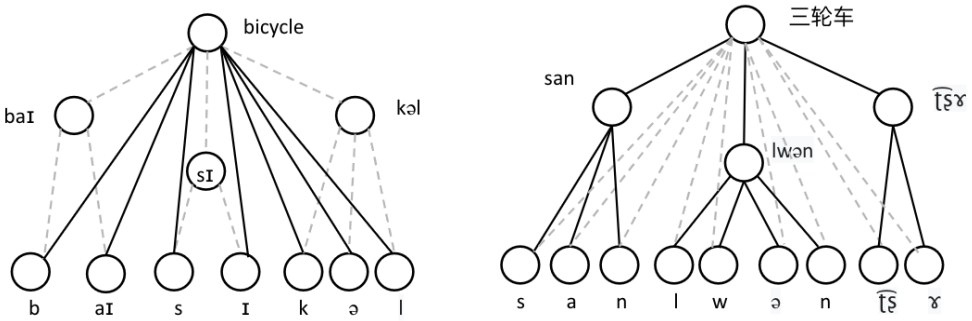
options, refer to 电 *dian4* (“electricity”), 店 *dian4* (“store”), 殿 *dian4* (“palace hall”), or 淀 *dian4* (“sediment”). Because there are comparatively few syllables and many homophones, Mandarin syllables usually have a high frequency compared to English syllables, which may modulate the importance of the Mandarin syllable in TOT priming relative to English (Abrams et al., 2003).

Given the special correspondence between morpheme and syllable, O’Seaghdha, Chen, and Chen (2010) assert that the syllable acts as the *proximate unit* in Mandarin. O’Seaghdha et al. (2010) define the proximate unit as the “first selectable phonological unit below the level of the word [that]...are pivotal in situations such as advance planning and partial preparation that involve continued coordination of phonological ingredients with their lexical origins” (282). Essentially, the proximate unit is the unit first selected during phonological encoding, the process by which a speaker retrieves a word’s sound form. O’Seaghdha (2015) specifically argues that the Mandarin proximate unit is the atonal syllable, a syllable without a tone (e.g. *dian* rather than *dian4*) which is technically unspeakable and can only exist as an abstract unit in the mind. O’Seaghdha (2015) additionally draws a distinction between proximate units in Mandarin and English, arguing based on successful speech production studies that English’s proximate unit is the phoneme. Although each language has a default proximate unit, O’Seaghdha (2015) states that form preparation may be flexible so that speakers can pay attention to different proximate units for specific tasks. Mandarin speakers and English speakers may have different proximate units due to their different orthographic structures: Mandarin characters are syllables, while English letters represent phonemes, and thus speakers of either language may be more naturally attuned to their respective proximate units. However, in specific cases like typing tasks, Mandarin speakers have been shown to orient themselves towards phonemes instead of syllables because typing requires them to input letters one by one on a keyboard (Chen & Li, 2011).

Placing O'Seaghdha (2015)'s proximate unit into the greater context of node structure, I posit that phonemes and syllables are both able to connect directly to lexical nodes. However, each language has a default proximate unit, the phonological unit that is automatically primed and activated after the lexical node (Figure 3). Other connections exist between phonological and lexical nodes, but they are not the first or strongest connections to be activated.

Figure 3

The proximate unit theory for English (left) and Mandarin (right)



Note. Solid lines show the default connections that are activated during speech production. Dotted lines show connections that exist but are not the default unless a specific task requires shifting to these connections.

The proximate unit in alphabetic languages seems to be the phoneme, as suggested by psycholinguistic studies in which the first phoneme facilitates speech production (Damian & Dumay, 2009; Levelt et al., 1999; Meyer, 1990, 1991; Schiller, 2000). In two well-cited studies, Meyer (1990) and Meyer (1991) studied speech production in Dutch, an alphabetic language similar to English. The study used an *implicit priming paradigm*, where participants learned sets of prompt-response word pairs. In homogeneous conditions, response words within the sets shared certain phonological characteristics—in Meyer (1990, 1991), words shared the first phoneme. For example, one set included the three word pairs "pond" - "kilo" (*pound* - *kilo*),

“insekt” - “kever” (*insect* - *beetle*), and “toren” - “koepel” (*tower* - *dome*), whose response words all shared the onset /k/. In heterogeneous conditions, the items in the set had no such phonological commonalities. The paradigm assumed that the first phonemes of the response words would be primed and facilitate phonological encoding in homogenous conditions, since participants would keep the recurring phoneme in mind when responding to prompt words. After learning the word pairs, participants were shown the prompt words and asked to produce the correct response words as quickly as possible. Response times were recorded, and participants responded significantly faster when a set of words shared the same first phoneme, regardless if the words were monosyllabic (Meyer, 1991) or disyllabic (Meyer, 1990). Thus, the studies indicated that speakers of alphabetic languages use individual phonemes to plan for speech production, as phoneme primes were able to facilitate response times. Notably, the facilitation effect did not occur when response words shared different phonemes with similar phonological characteristics (Roelofs, 1999). For example, the segments /b/ and /p/ are the same except for how they are voiced. Therefore, the locus of the facilitation effect occurs at the level of phonological encoding rather than at the level of physical speech production (i.e., articulation), indicating the importance of the mental representation of the phoneme in English speech production. Ultimately, these results point to the phoneme as an immediately accessible unit during speech production as well as the smallest unit available during this process, suggesting that it is the proximate unit.

A few studies using the *picture word interference paradigm* have suggested that the proximate unit in Mandarin is the phoneme, but these studies are not conclusive. In this paradigm, participants first familiarize themselves with a set of picture-name pairs and later are presented with pictures which they are asked to name as quickly as possible; in certain

conditions, they see or hear a distractor word prior to or after the picture that they are instructed to ignore, which may contain some overlapping quality with the image's name. Qu et al. (2012) studied whether phonemes act as a unit in Mandarin speech production using event-related potentials (ERPs), which provide detailed information about brain activity, in conjunction with a picture interference paradigm. Mandarin speakers named pictures of colored objects where the picture name and color word had the same first phoneme (e.g. 黄盒子 "yellow box" **h**uang20 **h**e2zi0) or no overlap. ERPs and response times to name the pictures were then measured. While there was no behavioral phoneme priming effect to support phonemic processing, shared phonemes modulated ERPs 200 to 400 ms after picture onset, a time course corresponding with previous ERP studies on when phonological encoding occurs. This ERP result suggested that Mandarin speakers process phonemic units during speech production. To bridge contrasting behavioral and ERP results, the authors proposed that a larger phonological unit (e.g., a syllable) may be more influential in Mandarin speech production and would affect behavioral responses, with phonemes individually processed in order to fill out this bigger, pre-established syllable unit.

Other picture-word interference studies also collectively suggested that the proximate unit of the phoneme does not differ between alphabetic languages and Mandarin. In a study by Jescheniak and Schriefers (2001) in German, participants saw images of objects and distractor words, which either shared or did not share the initial consonant-vowel phonemes as the object. For instance, a target word of *Stuhl* (chair) could have the phonologically related distractor word *Stube* (room) or the non-related distractor word *Erbse* (pea). Phonologically related distractor words showed reliable facilitatory priming effects, providing evidence that sub-syllabic units produce priming in alphabetic languages. Similarly, in Meyer and Schriefers (1991), participants

were shown images of objects with monosyllabic Dutch names and asked to name them while auditorily exposed to distractor words sharing the two beginning phonemes or the two ending phonemes as the objects. In both conditions, participants were able to name the objects more quickly than when exposed to distractor words with no phonological overlap. These results indicate that priming phoneme groups produce consistent benefits in alphabetic languages during speech production, whether those phonemes occur at the beginning or ends of words. Interestingly, picture-word interference studies in Cantonese, a Chinese language related to Mandarin, show that a similar facilitation effect occurs when the distractor word shares two of the same phonemes of the image's monosyllabic name (Wong & Chen, 2008, 2009, 2015). This facilitation effect casts doubt on whether the default proximate units in Mandarin or English may truly be different, since it suggests that phonemes can help in Mandarin speech production. However, further Mandarin and Cantonese studies show that no facilitatory effect occurs when only the first onset phonemes of words are shared (e.g., Chen & Li, 2011; Wong & Chen, 2008), even for monosyllabic words (O'Seaghdha, 2010). Because speech production in the NST model goes from left to right, it seems unlikely that the Mandarin phoneme is the first unit to be retrieved if the initial phoneme does not produce priming effects. The facilitatory effect for two phoneme primes may have occurred because of Cantonese's simple syllable structure which, like Mandarin, only allows for three phonemes in one syllable. By priming two phonemes of monosyllabic three-phoneme target words, Wong and Chen (2008, 2009, 2015) may have inadvertently primed the syllable nodes of a target word, as more than half of the syllable frame is already activated. Additionally, because Wong and Chen's (2008, 2009, 2015) experiments were conducted in Cantonese, one cannot assume that their results would apply for Mandarin.

Speech errors, which are influenced by the phonological traits of a language (Ecke, 1996; Garrett, 1993), also reveal discrepancies between English and Mandarin in their units of speech production. English syllable structure influences how phonemes move during speech errors. For example, syllable onsets (the first phonemes of a syllable) tend to move to other onset positions (Dell, Reed, Adams, & Meyer, 2000; MacKay, 1970), as in the misproduction *face spood* (intended: *space food*) from Fromkin (1971). This phenomenon, in which speakers tend to make phonemic speech errors, is also found in other alphabetic languages such as Dutch (Nooteboom, 1984). However, it is extremely rare for entire syllables in neighboring words to switch places (Dell, 1986; Levelt, 1989; Shattuck-Hufnagel, 1979). In contrast, Mandarin speech errors are more likely than alphabetic languages to involve entire syllables regardless of tone. In analyses of 120 recordings of a Mandarin radio call-in program, 10 syllable errors were found. For example, one such syllable error occurred with the phrase 清浊度 qing1zhuo2du4, in which the phrase was pronounced as qing1du2du4 with the "du" anticipatorily produced instead of "zhuo." Although the number of syllable errors was low, the fact that these types of errors occur—at a rate 10,000 times higher than would be expected if the errors occurred from independent phonemic errors—provides evidence that syllables function as discrete phonological units during Mandarin language production (Chen, 2000). Additionally, because syllables exchanged places but maintained the same tone as the original word, it is likely that an atonal syllable exists as a phonological unit during speech production.

From a computational linguistics angle, Chen et al. (2003) used simple recurrent networks in Mandarin and English to study statistical patterns of sound sequences in both languages, to determine whether "the role of the syllable is...equally emphasized in the production of Mandarin and English." The networks were trained with Mandarin and English

data from children's media and used to predict word-initial sounds, syllable-initial sounds that were not also word-initial, and within-syllable sounds. In Mandarin, regardless of the time spent training or whether tones were taken into account, within-syllable sounds were the most difficult to predict, while syllable-initial and word-initial sounds were equally difficult to predict. In other words, the model was able to accurately predict the beginnings and ends of syllables but not the individual phonemes within the syllables. Chen et al. (2003) argues that these results indicate extremely salient syllable boundaries in Mandarin, providing evidence that the syllable acts as a distinct unit within Mandarin. In contrast, English models in the study yielded far less salient syllable boundaries, predicting initial syllable sounds at accuracies closer to within-syllable sounds than word-initial sounds.

Meanwhile, from a neuroscientific perspective, Feng et al. (2019) conducted an ERP study in Mandarin that indicated that syllables are temporally retrieved before other phonetic segments in speech production. The study used a picture-word interference task in which participants saw pictures along with distractor words that shared the picture's same syllable, the same body (first two phonemes), the same rhyme (last two phonemes), or no phonological properties. In their analysis of ERP data, they found that a syllable priming effect (320-500 ms) occurred before the body priming effect (370-420 ms), which occurred before the rhyme priming effect (400-450 ms). Mirroring the proposal put forth by Qu et al. (2012), these results indicate that speakers retrieve syllables first in word form encoding and then assemble internal phonemic segments from left to right. These results strongly support the syllable as the Mandarin proximate unit, because the syllable unit is encoded first in language production, followed by phonemes.

Behavioral research methods using an implicit priming paradigm similar to Meyer (1990, 1991) further suggest that Mandarin syllables act as proximate units (Chen et al., 2002; Chen & Chen, 2013; O'Seaghdha et al., 2010). Chen et al. (2002) investigated the priming effects of the character, syllable, phoneme, and tone. In a series of five experiments, participants learned sets of disyllabic Mandarin words, in which response words were semantically related to prompt words (e.g., a prompt word 航空 *hang2kong1* ("aerospace") and a response word 飞机 *fei1ji1* ("airplane")). In homogenous conditions, the first characters of the prompt word and response word were the same (Experiment 1a); shared the same syllable and tone (Experiment 1b); shared the same syllable but not tone (Experiment 2); or shared the first phoneme (Experiment 5). In heterogeneous conditions, the prompt words had no phonological overlap. Afterwards, participants were visually presented with prompt words in homogeneous and heterogeneous sets, and they produced the corresponding response words as quickly as possible. Relative to the heterogeneous conditions, facilitation occurred when response words shared the same character or the same first syllable (regardless of tone), but did not occur when response words shared only the same tone or the same first phoneme. The fact that syllables created priming effects regardless of tone indicates the existence of an abstract proximate unit of an atonal syllable in Mandarin. Moreover, as syllables' meanings are determined by tone, the syllable priming effect is therefore not confounded by morphemic priming. Later, O'Seaghdha et al. (2010) successfully replicated the experiments conducted by Chen et al. (2002) in Mandarin and extended the experiments in English. O'Seaghdha et al. (1) replicated the lack of first phoneme priming in Mandarin observed by Chen et al. (2002) with both disyllabic and monosyllabic word pairs, (2) replicated a facilitation effect in Mandarin from atonal syllable priming (also replicated later in Chen & Chen, 2013), and (3) showed that first phoneme priming occurred in English with even

monosyllabic words. Together, these results indicate that priming syllables helps with Mandarin speech production but that priming phonemes does not, in direct contrast with the implicit priming studies conducted by Meyer (1990, 1991) in Dutch.

Studies utilizing the *masked priming paradigm* also show contrasting results between Mandarin and non-Mandarin syllables in speech production (Chen, Chen, & O'Seaghdha, 2016; Chen, Lin, & Ferrand, 2003; Perret, Bonin, & Meot, 2006; Schiller, 1998; Schiller, Costa, & Colomé, 2002). In this paradigm, before seeing a target word or image, participants are exposed to a prime which is masked—or hidden—by virtue of appearing extremely quickly and often between two random strings. This set-up prevents participants from being able to use conscious strategies regarding primes during experiments that may influence results. In one study in Mandarin conducted by Chen et al. (2016), participants were exposed to masked primes that either shared the first syllable or the first phoneme of an object. They then were presented with an image of an object and said its name as quickly as possible. As predicted, first syllable primes created a facilitatory effect in speech production relative to the first phoneme primes. In fact, first phoneme primes had a marginal inhibitory effect, which the study suggested might be due to the phonemes simultaneously activating many syllables or words. A similar facilitatory syllable priming effect in a masked priming paradigm was also found in Chen et al. (2003). On the other hand, only one study by Ferrand et al. (1996) showed a robust syllable priming effect in a masked priming paradigm in French; subsequent studies have attempted and failed to replicate this finding with the same magnitude in various alphabetic languages, including in Spanish and Dutch (Perret, Bonin, & Meot, 2006; Schiller, 1998; Schiller, 2000; Schiller, Costa, & Colomé, 2002). Overall, behavioral studies of the Mandarin syllable demonstrate that the syllable produces reliable priming effects, in contrast with syllables of alphabetic languages. Because the

syllable is readily retrievable during speech production, more so than the phoneme, it seems to be the first unit to be phonologically encoded. Given the uniquely important role that the syllable plays in Mandarin, the current study seeks to explore how Mandarin phonology influences TOT incidence and resolution.

Mandarin orthography

There have been no studies which examine how orthography, separate from phonology, influences TOT states, as researchers have assumed that TOTs are a purely phonological phenomenon. However, NST also includes an orthographic system, which remains unaccounted for in current TOT studies. MacKay and Abrams (1998) extended the original NST model proposed by MacKay and Burke (1990) to develop a more detailed theory for how orthography interacts with other nodes (see right side of Figure 1). Like phonological nodes, orthographic nodes are connected bottom-up to lexical nodes and top-down to muscle movement nodes (for writing and typing). Phonological nodes and orthographic nodes are laterally connected from phoneme to letter so that people can spell words that they have not learned before based on the phonemes that they hear. Because English letters match to various phonemes, MacKay and Abrams (1998) proposed a way to represent "regular" and "irregular" spellings of a phoneme in the orthographic system. The "regular" spelling of a speech sound is the letter that most often represents it, with alternate letters being "irregular" forms of spelling. For example, the speech sound /ər/ in *baker* is regularly spelled because most nouns (teacher, worker) use "er" to represent it, but it is spelled irregularly in *cellular* as "ar." To account for multiple spellings, MacKay and Abrams (1998) propose that a "quasi-irregular node" mediates between the lexical node and orthographic nodes, which contains information about whether or not a lexical item has an instance of irregular spelling. When a word with irregular spelling such as "cellular" is

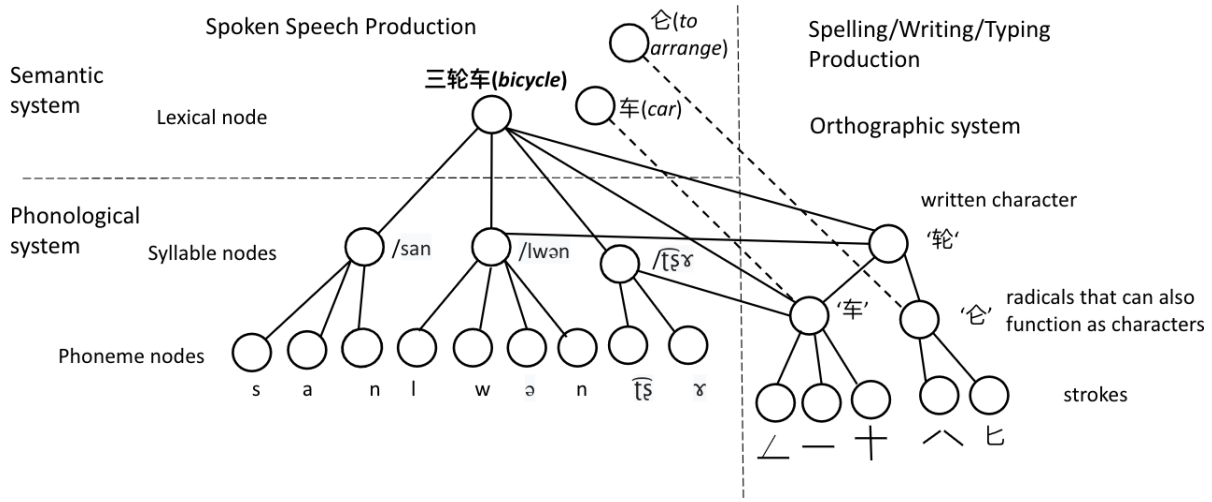
activated, the “quasi-irregular node” primes orthographic nodes in a top-down fashion; in the case of *cellular*, the “quasi-irregular node” inhibits the orthographic node /e/ and excites the orthographic node /a/. Thus, the correct orthographic information for *cellular* can be retrieved if it has been memorized as an exception to the typical spelling of /ər/.

However, this proposed system centers alphabetic languages, in which there is a lateral phoneme to letter correspondence that cannot exist in Mandarin. This system does not take into account unique features of Mandarin such as radicals, basic orthographic units within characters that are often used in experiments to elicit orthographic priming effects. Radicals are used to categorize Chinese characters in the dictionary; therefore, they are used as orthographic primes because they are the “next step” below characters, in which individual strokes of a character can still be clearly grouped. For example, the word 红 hong2 (*red*) is composed of the radical 纟 and the radical 工. Radicals can be placed horizontally as in the previous example, or vertically as in the word 兄 xiong1 (*older brother*), which consists of the radicals 口 and 儿. Radicals also have two different categories: semantic and phonological radicals. For instance, the semantic radical 女 also functions as the character nü3 (*girl*), and when this radical is used in conjunction with other radicals, it shows that the holistic character has a meaning that tends to be associated with femininity. In another example, the phonological radical 马 tends to be associated with the syllable “ma”. Thus, put together, the radical 女 and the radical 马 form the word 妈 ma1 (*mother*). However, some radicals do not contain such strongly associated phonological and semantic meanings, and thus neither category of radicals definitively indicate the meaning or the sound of a character. Radicals therefore can be used to control for the phonological and the semantic overlap between primes and target words, and thus serve as primes in many studies on orthographic effects independent from phonology and semantics.

I posit an orthographic model for Mandarin, where Mandarin characters are connected with phonology at the syllable level instead of the phoneme level (Figure 4). Syllables connect laterally to character nodes, which are broken down into radicals that may or may not also function as characters. Radicals are further broken down into strokes, the individual lines that make up a radical. Notably, there are more connections between the Mandarin phonological and orthographic systems than in English due to the complex nature of radicals, as semantic radicals connect to the semantic system, phonological radicals connect to the phonological system, and radicals that also function as characters connect to semantic and phonological nodes.

Figure 4

Diagram of Mandarin speech production based on NST for the lexical node 三轮车, meaning 'bicycle'



Note. The solid lines between the phonological and orthographic system show how syllable nodes /lwən/ and /ʈʂɤ/ respectively connect to the characters 轮 and 车 (三 is omitted for simplicity). The dotted lines show how semantic radicals 车 and 仑 that comprise the character 轮 respectively connect to the semantic nodes "car" and "to arrange." Neither of these radicals are phonological radicals such as 里, which is sometimes associated with the sound /li/ and would be connected to a phonological node instead of a semantic node.

Studies using the picture-word interference task have shown that orthography facilitates Mandarin speech production (Qu & Damian, 2019; Zhang et al., 2009; Zhao et al., 2012). In two experiments conducted by Qu and Damian (2019), participants were asked to familiarize themselves with pictures of objects in one of four colors and their descriptions, target words consisting of an adjective and a noun. In related conditions, the adjective, which was the color of the objects, and the noun, which was the name of the objects, shared the same radical (e.g. 蓝, lan2, *blue*; and 花瓶, hua1ping2, *flower vase*; which share the radical 艹). Meanwhile, in control conditions, the adjective and the noun did not share the same radical. Then, participants were shown the pictures and asked to name them as quickly as possible. In both experiments, which only differed slightly in the materials used, participants named objects faster when the adjective and the noun shared a radical, suggesting that shared orthography facilitates speech production. In a similar paradigm, Zhang et al. (2009) showed target pictures of objects and their monosyllabic Mandarin names to participants before beginning the PWI task. During the PWI task, the study varied the onset of a Mandarin distractor word to occur 150 ms before, during, or 150 ms after the picture was shown. Distracter words belonged to one of five conditions: phonologically related (sharing the same syllable), orthographically related (sharing a radical and the general structure of the character), phonologically and orthographically related, semantically related, and unrelated. Results showed that phonologically related words facilitated picture naming when they occurred during or 150 ms after the picture, while orthographically related distractor words facilitated picture naming at all three time points at greater magnitudes. Additionally, the phonologically and orthographically related distractor words showed magnitudes of facilitation that were additive of the only phonologically related and only orthographically related words. These results indicated a strong and consistent orthographic

effect in facilitating speech production in Mandarin, which works independently of a smaller phonological facilitation effect.

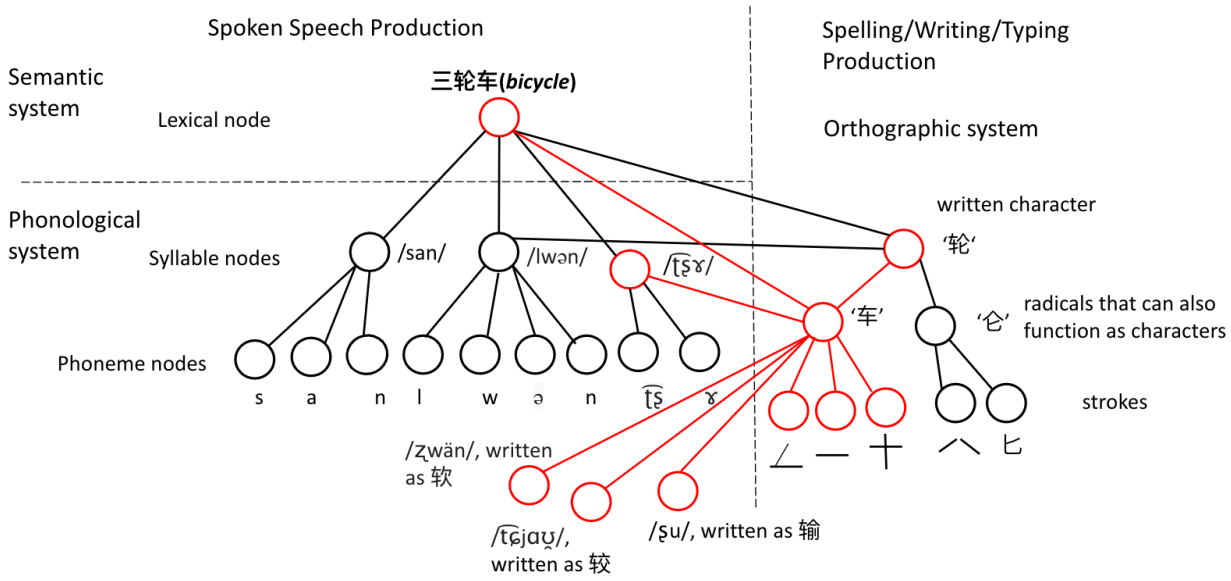
However, Mandarin implicit priming paradigms have shown inhibitory effects of orthography, contrary to the facilitatory effect of orthography in picture-word interference paradigms and to the facilitatory effect of phonology in implicit priming tasks (Bi et al., 2009; Chen et al., 2002; Chen & Chen, 2013; Meyer 1990, 1991; O'Seaghdha et al., 2010; Zhang & Damian, 2012). Zhang and Damian (2012) found an inhibitory effect in a study that asked participants to learn prompt-response word pairs in which responses shared the same radical but were phonologically different (homogeneous condition), or word pairs with no orthographic or phonological overlap in responses (heterogeneous condition). They were then asked to respond to a prompt word as fast as possible. The study found an orthographic inhibitory effect: response latencies in the homogenous condition were longer than the heterogeneous condition. Bi et al. (2009) also observed a small inhibitory effect using a variant of the implicit priming task. In a learning session, participants read aloud 12 triplets of words in sequence that either shared both orthography (the same radical) and phonology (the same initial syllable) (e.g., 沙发 , "sha1fa1," *sofa*; 砂子, "sha1zi," *sand*; 纱布, "sha1bu4," *gauze*); only phonology (e.g., 珍珠 , "zhen1zhu1," *pearl*; ,侦探 "zhen1tan4," *detective*; 针管, "zhen1guan3," *needle*); or only orthography (e.g., 蜡烛, "la4zhu2," *candle*; 醋瓶, "cu4ping2," *vinegar bottle*; 借条, "jie4tiao2," *receipt*). As opposed to the classical implicit priming paradigm in which prompt words are associated with responses, in the following experimental task participants did not see any prompt words. Instead, they were simply shown one word from each triplet at a time and asked to read it aloud. The naming latencies were longest on average when participants read triplets that shared only orthography.

Although it is surprising that sharing only orthography in the implicit priming paradigms led to inhibitory effects, it is possible that this effect arose not from the language production processes but from learning sessions in this particular task. In an implicit priming experiment, participants are asked to learn the words beforehand. During the learning stage, participants may use orthography to better memorize word pairs when seeing that certain word pairs have shared radicals (Zhang & Damian, 2012) or simply grow to associate words with each other because of their shared orthography (Bi et al., 2009). However, a key point to note is that Mandarin radicals are connected to characters with multiple pronunciations (see Figure 5). During the experiment, participants may try to use orthography to recall correct response words or anticipate the next word to read aloud. However, the shared radicals actually prime several phonological nodes that can compete with each other for retrieval, causing an inhibitory effect. In fact, when participants did not see the word pairs during the learning or testing stages and subsequently did not notice and strategically use the radical overlap between certain word pairs, the inhibitory orthographic effect disappeared (Zhang & Damian, 2012). Ultimately, the key difference between why orthography creates an inhibitory effect and phonology creates a facilitatory effect in implicit priming paradigms is due to the unique linguistic properties of Mandarin. Phonological nodes are drawn upon directly for speech production, but Mandarin orthographical nodes connect to an array of phonological nodes that inhibit rather than speed up the process. During implicit priming paradigms, a radical can be used in multiple word pairs, so that the connections between that radical and multiple phonological nodes are primed. However, the facilitatory effect found in the PWI paradigm can be accounted for in that participants do not need to memorize multiple word pairs sharing the same radical. No competing phonological nodes are primed: there is simply one

target word and one image whose name shares a radical with the word, priming that one specific connection between phonology and orthography.

Figure 5

Diagram of the Phonological Nodes Connected to 车



Note. The nodes and connections immediately connected to the radical node 车 are highlighted in red. When participants use 车 for recall, 车 maps onto various phonological nodes that can cause competition.

Current study

The current study includes two experiments on how native Mandarin speakers experience the TOT phenomenon. The first experiment investigated how TOT states function in Mandarin and whether phonological primes and their first syllable frequencies affect TOT incidence and resolution. The results will help to determine whether those processes are analogous to English or are language-specific due to the proximate unit theory. Because the proximate unit seems to influence the realm of successful speech production, it will likely affect word retrieval during TOT states that represent a breakdown in the phonological encoding process. For example, it may affect the strength of the priming effect—depending on the type and number of proximate

units activated—or the type of partial information that is retrieved during TOT states. If our findings support the proximate unit theory, then much of previous TOT literature in alphabetic languages would need to be reexamined, and if phonology influences Mandarin TOTs differently, NST would need to be expanded to account for various languages' proximate units. For example, first syllable facilitatory effects found in TOT states in alphabetic languages may instead be interpreted as an effect of multiple proximate units receiving priming. For example, if a subject in a TOT state for the target word (e.g., *binary*) is primed with *bicycle,* which shares the first syllable, *bicycle* will prime many words beginning with /b/, while also priming many words whose first syllable's vowel is /aɪ/. Overall, words beginning with 'baɪ' will receive the most priming compared to other words which either only begin with 'b', contain 'aɪ', or do not share anything with *bicycle* at all. Thus, the target word receives substantially more priming compared to those words that do not share the whole first syllable with the prime, and hence is more likely to be retrieved.

This explanation, in which multiple phonemes are primed simultaneously, can also be used for understanding what Farrell and Abrams (2011) called the first-syllable frequency effect on TOT states. For example, let us assume that the syllable /baɪ/ is high-frequency, while the syllable /om/ is low-frequency. The phonemes /b/ and /aɪ/ prime lexical nodes whose first syllables contain either or both of these phonemes, with nodes containing both phonemes getting the most priming. A similar process happens with /om/. However, since there are more lexical nodes that contain /baɪ/, the lexical nodes containing /baɪ/ will each receive less priming than lexical nodes containing /om/, resulting in more TOT states for the first syllable /baɪ/. Thus, the first syllable frequency effect may actually be more accurately described as an effect caused by sharing multiple phonemes. Moreover, if there are many lexical nodes containing /baɪ/ as its first

syllable, some of them are likely to be higher in word frequency than the target. Therefore, links from the phoneme nodes to these higher frequency words will be stronger and better for transmitting node priming relative to the link with the target.

In the second experiment, we focused on how pure orthography might affect TOT incidence and resolution, a question that has not yet been explored. Previous studies on TOTs in alphabetic languages assumed that phonology by itself affected TOT states, but because the prime words in these languages usually "spelled out" how they sounded, orthography may have been a confounding variable as there was simultaneous priming of both the phonological and orthographic overlap with the target. Thus, we are curious whether orthography by itself might affect TOT states, especially given Mandarin's unique orthographic system in which radicals create multiple connections between the orthographic, semantic, and phonological systems. Overall, through our study, we hope to gain a more nuanced understanding of the TOT phenomenon by using Mandarin to examine the idea of the proximate unit and to tease apart phonological and orthographic effects.

Hypotheses: The Role of Phonology

We will test whether first phoneme primes and first syllable primes lead to greater rates of TOT resolution. Based on studies in English, it is unlikely that the phoneme will create a priming effect. However, we included this condition because if the phoneme *does* show an effect, we know that the phoneme functions as an important phonological unit available during Mandarin speech production, which would provide evidence against the proximate unit theory. For the syllable condition, we hypothesize that a first syllable priming effect may emerge in Mandarin based on Ouyang et al. (2020) and previous TOT studies in English and other alphabetic languages. The Mandarin syllable may function similarly to the English syllable, as

both contain more phonological information than one phoneme. In the case of TOT states, the Mandarin syllable may still provide the necessary information for word retrieval that the English syllable does, since priming the Mandarin syllable would similarly narrow down the possible lexical nodes to activate. Furthermore, a high frequency syllable may show a similar effect in Mandarin as in English, where high syllable frequencies result in lower rates of TOT resolution.

Alternatively, Mandarin speakers may not receive the same benefits as English speakers with a syllable prime. We note that the act of priming phonemes—the proximate units of English—does not facilitate TOT retrieval (Abrams et al., 2003), suggesting that TOT states may require more than one proximate unit for successful resolution. Given that the Mandarin proximate unit is the syllable, Mandarin speakers may need more than a syllable prime to resolve TOT states just as English speakers need more than a phoneme prime. Especially because the small number of Mandarin syllables is linked to the high number of homophones, priming a syllable may lead to weak activation of many homophones, none of which would reach the threshold for successful retrieval. Ultimately, the word causing the TOT state would also receive insufficient activation, leading to failed TOT resolution. Thus, while studies based on English phonology demonstrate a robust first syllable priming effect (Abrams et al. 2003), TOT resolution in Mandarin may show either a small or nonexistent first syllable priming effect.

First syllable frequency may influence TOT incidence in Mandarin speakers. Specifically, words with a low frequency first syllable may have higher rates of TOT states. Although this effect was only observed in older adults and not in younger adults in Farrell and Abrams (2011), we hypothesize that the effect may occur with younger Mandarin speakers. Because Mandarin syllables are morphemic and tied to individual characters, Mandarin speakers may be more attuned to syllables and their relative frequencies, with the most frequently used syllables having

the strongest bonds to lexical nodes. Thus, first syllable frequency may be a more important and influential factor on their speech production. It is also possible that first syllable frequency will not affect TOT incidence. Because Mandarin syllables generally occur at a higher frequency than English, the relative difference between frequencies of low and high frequency words would be smaller in Mandarin than in English, and thus their frequencies may not significantly modulate TOT incidence. On the other hand, syllable frequency may also affect TOT resolution. If Mandarin speakers are more sensitive to and affected by syllable frequencies during speech production, then we may see a similar effect as in Farrell and Abrams (2011) where a lower syllable frequency leads to more TOT resolution. However, given the high number of homophones that Mandarin syllables have in general, syllable frequency might also not strongly affect TOT resolution, because every syllable has multiple phonological competitors.

Finally, the proximate unit may affect the types of partial information that speakers retrieve during failed speech production. Studies already show that English speakers can often recall the first phoneme in TOT states in experimental and diary studies (Abrams et al., 2003; Brown, 1991; Ecke, 1996), indicating the speakers can retrieve phonemic proximate units during failed speech production. On the other hand, O'Seaghdha et al. (2010) speculated that Mandarin speakers would be more likely to recall entire syllables in TOT states rather than individual phonemes given that Mandarin proximate units are syllables, a hypothesis that remains unconfirmed. If the proximate unit theory is true, our experiment will show that participants can most often partially retrieve syllables of target words rather than phonemes. Additionally, Chen (2000) observed that whole Mandarin syllables can move during speech errors. Thus, during TOT states, participants may recall syllables in cheng-yus in switched positions, which would provide further evidence for the syllable as a planning unit in mandarin. We also predict that if

participants are exposed to first phoneme or first syllable primes in TOT states, they would more frequently recall the first phoneme or character of the target. Under node structure theory, giving the first phoneme or first syllable prime would prime these nodes, facilitating the retrieval of these pieces of partial information even if the entire cheng-yu is not recalled.

Hypotheses: The Role of Orthography

Previous studies have shown varying effects of orthography in other experimental paradigms, with orthography creating facilitatory or inhibitory effects depending on how many connections between orthographic and phonological nodes are active. What would this mean for the current tip-of-the-tongue study? First, given that the TOT state occurs from weakened connections between phonological nodes and lexical nodes, a prime with orthographic information (i.e., the first radical) may not be useful for strengthening these connections. If orthography cannot sufficiently prime weakened phonology, then it would not facilitate TOT resolution. Different from the PWI and the implicit priming paradigms where subjects readily observe similarities in orthography among visually presented words, the target word in TOT state is hardly accessible, and shared orthography via a prime may not help as much in TOT incidence or resolution. On the other hand, given that Mandarin characters have individual meanings and several homophones, Mandarin orthography has several connections with phonological and lexical nodes. Priming orthography could potentially provide activation to several nodes at once, which then collectively activate the phonological nodes needed for target retrieval. If the orthographic system is activated by speech production, participants' partial recall should not only include syllables of the cheng-yu but the correct corresponding characters. If participants frequently recall homophones of the syllables rather than the exact characters, this would point to a lack of activation of the orthographic system.

Because of the unique nature of the Mandarin radical which connects to multiple nodes, it is possible that TOT states can be influenced by the frequency of the first character's orthography, specifically radical frequency. Previously, a high syllable frequency has been shown to affect TOT incidence and resolution in English speakers (Farrell & Abrams, 2011). A high frequency radical may also yield an effect on TOT states based on the model in Figure 5. In general, radical nodes would prime many different orthographic, lexical, and phonological nodes, which may continue to spread priming until it reaches the phonological nodes of a target lexical item. For example, in Figure 5, the radical node 车 connects to the phonological nodes /t͡ʂɤ/, /ʐwän/, /t͡ɕjɑʊ̯/, and /ʂu/, which may dilute the phonological priming needed to retrieve the target, 三轮车 (*bicycle*). However, the radical node 车 also connects to the orthographic node 轮 and the target lexical item 三轮车, which both connect to the phonological nodes that need to be retrieved, /san/, /lwən/, and /t͡ʂɤ/. If 车 is a high frequency radical, it is used more often and its connections with other nodes is stronger, allowing for priming to efficiently spread through its multiple nodes until the phonological nodes for 三轮车 are retrieved. This priming would be diffused because it needs to pass through a couple different nodes in order to get to the correct phonological nodes. However, the number of nodes that pass on priming may be high so that they collectively activate the proper phonological nodes. Radicals with higher frequencies may create stronger connections between nodes, which leads to less TOT incidence, and also efficiently spread priming to increase instances of TOT resolution. On the other hand, we may see a lack of radical frequency effect on TOT incidence and resolution if orthographic priming is too diluted for both low and high frequency radicals. A radical node may activate so many nodes that priming is diffused to the point that very little of it reaches the phonological nodes needed for lexical retrieval.

Experiment 1

Methods

Participants

54 native Mandarin speakers (43 female, 11 male; mean age 20.29 years, *SD* = 2.27; 47 right-handed, 1 left-handed, 3 ambidextrous, 3 unknown) were tested at East China Normal University in Shanghai. All participants were university students residing in the general Shanghai area who reported that their first and only native language, as well as their most dominant language, was Mandarin. All participants reported no health problems and normal to corrected eyesight. To recruit participants, posters advertising the experiment were posted on WeChat, a Chinese social media platform. Participants scanned a QR code on the poster to join a WeChat group created for the experiment, where they signed up for experiment sessions through a timesheet sent out every week. They were reimbursed monetarily (60 RMB ≈ $9) for their participation.

Because the Chinese education system requires students to learn English, participants filled out a subset of the Mandarin version of the LEAP-Q (Language Experience and Proficiency Questionnaire) developed by Marian, Blumenfeld, and Kaushanskaya (2007), which collects information about bilingual speakers' language proficiency and experience. The LEAP-Q showed that all participants were at least bilingual, with almost half being multilingual (see Table 1). All participants were proficient in English, with most having acquired it during childhood (mean age of acquisition = 7.31 years, SD = 2.39; see Table 2 for self-rated English proficiencies). The majority of participants continued to regularly engage in their native language of Mandarin (see Table 3). All except one participant reported that they preferred using Mandarin when interacting with others and reading text. Besides Mandarin and English,

multilingual participants reported learning Spanish, French, German, Japanese, and Italian, although none before the age of 10 or with native-like fluency.

Table 1

Number of Languages that Participants Learned in Experiment 1

Number of Languages Learned	Number of Participants
2	34
3	16
4	3
5	1

Table 2

Participants' Self-Rated English Proficiencies in Experiment 1

Self-Rated English Proficiency	Mean	Standard Deviation
Speaking proficiency	6.17	1.98
Comprehension proficiency	6.57	2.09
Reading proficiency	7.26	1.88

Note. 1 indicates not being proficient and 10 indicates being most proficient.

Table 3

Participants' Exposure to Mandarin in Everyday Life in Experiment 1

Percentage of Time Exposed to Mandarin	Number of Participants
Below 50%	2
50-60%	4
60-70%	10
70-80%	10
80-90%	11
90-100%	17

Materials

For the TOT target words, we selected 100 cheng-yu (成语 in Mandarin) targets. Like words that contain syllables in English, cheng-yus function as one lexeme and have fixed internal characters that cannot be switched out without modifying the meaning (Wu, 1995). For example, all the characters within the cheng-yu 仗义疏财 zhang4yi4shu1cai2 ("to help the needy for the sake of justice") must be present in the exact listed order to form a word. Many cheng-yus occur at low frequency but have extremely specific definitions, making them ideal candidates for questions meant to induce TOT states. Additionally, using cheng-yus enables a degree of control over primes that does not exist in English. While studies in alphabetic languages tended to use target words of varying syllable length, using cheng-yus controls for the number of syllables in each target word because all cheng-yus are four syllables. Moreover, because re-syllabication occurs extremely infrequently in Mandarin as opposed to English (Chen et al., 2002), the characters within a cheng-yu will not resyllabify, and syllable primes will prime exactly one set syllable.

For each target, a question that described the cheng-yu's meaning was created in an attempt to induce TOTs. Two possible two-character prime words were created for a target: (1) a prime that shared the target's first phoneme (e.g., 制定 zhi4iding4 for the target cheng-yu 仗义疏财 zhang4yi4shu1cai2, where "zh" represents one phoneme), and (2) a prime that shared the target's first syllable but with a different orthography, i.e., the prime's first character was a homophone with the same tone and no orthographic overlap (e.g., 帐子 zhang4zi0). A word with no morphological or phonological overlap with the target (e.g., 联盟 lian2meng2) was created as an unrelated control. Four filler words were created for each target consisting of two- or three-character words with no semantic, phonological, or morphological overlap with the cheng-yu. All of the above stimuli are displayed in Appendices A and B.

Once all 100 target questions were presented, participants took a multiple-choice recognition test to determine whether participants truly knew the correct target answers. All unresolved questions (i.e., any question that was not answered "I know the target word" on the first or second presentation) were presented with four possible answers: (1) the correct target (仗义疏财 zhang4yi4shu1cai2 "to help the needy for the sake of justice"), (2) a semantically and phonologically related cheng-yu (e.g. 仗义执言 zhang4yi4zhi2yan2 "to speak out from a sense of justice."), (3) a semantically related but phonologically unrelated cheng-yu (e.g. 散尽千金 san4jin4qian1jin1 "to disperse wealth"), and (4) a cheng-yu with no semantic or phonological overlap (e.g. 日月同辉 ri4yue4tong2hui1 "the sun and moon are similarly splendid"). Each of the choices was presented with the letter A, B, C, or D, which participants used to select their answer. The target position was counterbalanced so that it appeared equally often in the four possible answer choices across all 100 questions. Appendix D shows the multiple-choice recognition answer choices.

Three pre- and post-experiment questionnaires were given to all participants. The first pre-experiment questionnaire (see Appendix E) asked about participants' demographic information, health, and previous experience with various languages. The second pre-experiment questionnaire was a subset of the Mandarin version of the LEAP-Q (Marian et al. 2007), which assessed participants' language backgrounds (see Appendix F). The post-experiment questionnaire (see Appendix G) checked whether participants guessed the intention of the experiment or the relation between the target words and the prime words, as well as if they used that relation to facilitate their retrieval of target words.

Design and Procedure

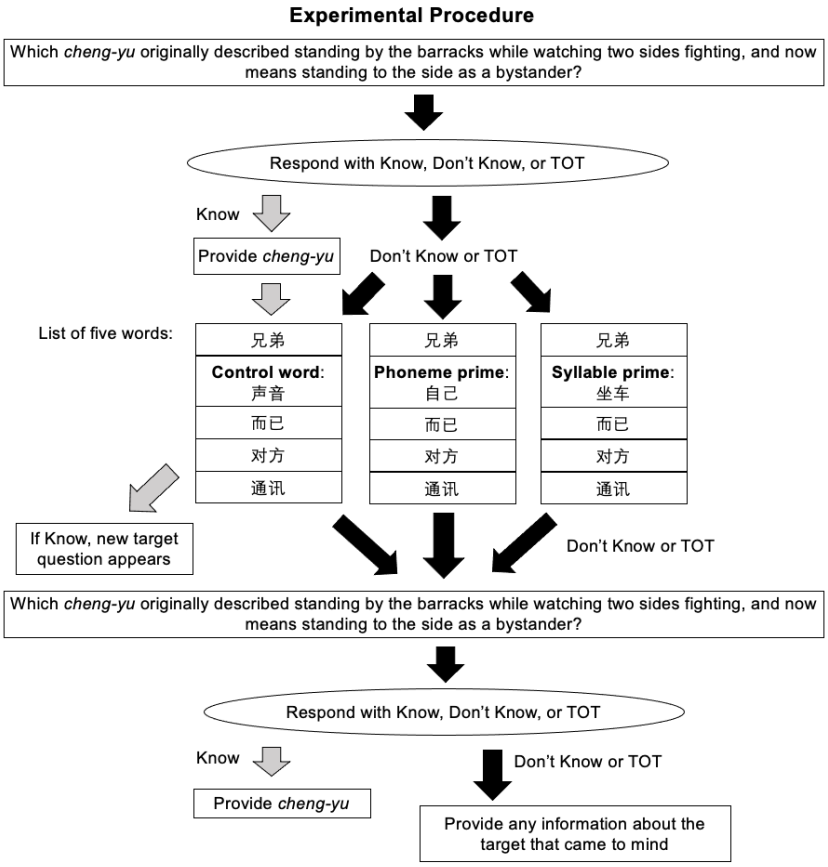
The entire experiment—including participant instructions, questionnaires, the computer program, and any verbal interactions with the participant—was conducted in Mandarin. The experiment was based on the experimental paradigm used by Abrams et al. (2003) and included one within-participants factor, priming condition, with three levels (first phoneme primes, first syllable primes, and unrelated control words). Before the experiment, participants filled out the pre-experimental surveys. Then, they were given a printed sheet which had an explanation of the TOT phenomenon as well as instructions on the tasks that they would complete during the experiment. The TOT phenomenon was described as follows (translated from Mandarin):

> "When a tip-of-the-tongue state happens, you know the cheng-yu's definition, as well as when and how to use the cheng-yu in a sentence. You might know the first character/ word or how it sounds. The tip-of-the-tongue state is different from feeling like you *should* know the word. In a tip-of-the tongue state, you might feel the cheng-yu is on the tip of your tongue, and you might feel frustrated that you can't think of the cheng-yu."

After confirming that participants understood what a TOT was, participants began the experimental procedure, which is outlined in Figure 6. Participants saw target questions one-by-one in the center of a computer screen. After reading each target question, participants responded by typing “Z” (知道 zhi1dao4 for “Know”) if they knew the target word, “B” (不知道 bu4zhi1dao4 for “Don’t know”) if they did not know the target word, or “S” (舌尖现象 she2jian1xian4xiang4 for “TOT”) if they were experiencing a TOT state. Afterwards, participants saw five words one at a time and rated each word for how frequently they encountered the word on a 10-point scale, with 1 being that they never encountered it to 10 being that they encountered it every day. The second word in the list was either a prime or a control, and the other words were fillers. If the participant selected “Know” after reading the question, they were prompted to type in the answer, and then saw a five-word list which always contained the control word. After rating all of the words, a new question was presented. If the participant selected “Don’t Know ” or “TOT,” the computer program randomly selected which of the three priming conditions were shown, with the constraint that all three conditions were selected before repeating one of them. After rating the words, the previous target question was re-presented, and participants were asked to answer it again with “Know”, “Don’t Know”, or “TOT.” If participants entered “Know”, they were asked to type in the correct answer. If they entered “Don’t Know” or “TOT”, they were asked to type in any information they could remember about the target word, including the first word/character, another cheng-yu, or words that came to mind. The next question was presented, and the above procedure was repeated. After seeing all 100 target questions, participants completed the multiple-choice recognition test and the post-experimental survey. The entire experimental session lasted approximately an hour and a half.

Figure 6

Diagram of the Experimental Procedure for Experiment 1



Note. In the list of five words, the bold label indicating the 2nd word in the list is shown here for clarity but was not shown during the actual procedure.

Results

We excluded three participants from analyses due to the computer program terminating prematurely. The remaining 51 participants' responses to the post-experimental questionnaire were reviewed to see whether participants were aware of being primed and used the prime words to retrieve the target cheng-yu. Out of 51 participants, 38 (74%) said they did not notice a relation between the prime words and the target questions, and 12 participants (23%) guessed an incorrect relation between the prime word and the target questions (e.g., they were synonyms or

semantically related to the cheng-yu). Only one participant reported a phonological relation between the primes and target questions, although they could not recall or describe how they used this relation to intentionally recall target cheng-yu. We chose to include this participant in our analyses, as previous research using repeated prime words has shown that intentional, explicit retrieval strategies are more important than mere awareness in influencing priming effects (Bowers & Schacter, 1990; McKone & Slee, 1997). Prior to analysis, we defined outliers as participants who had fewer than six TOTs, i.e., did not have at least two TOTs in each of the three priming conditions, to ensure the mean resolution in each priming condition was based on more than a single TOT. This criterion resulted in the exclusion of six participants for all analyses.

The initial responses to the target questions were categorized into five possible responses: correct “Know”, incorrect “Know”, correct “TOT”, incorrect “TOT”, and “Don’t Know”. Correct “Know” responses (25%) were responses where participants indicated knowing the answer and then retrieved the target, while incorrect “Know” responses (20%) occurred if participants indicated knowing the answer but retrieved an answer other than the target. “TOT” responses (18%) were categorized as correct when participants provided the correct answer to the target question on its second presentation or chose the correct response for the multiple choice recognition test; otherwise, “TOT” responses were designated as incorrect (4%). Finally, “Don’t Know” (33%) responses occurred when participants selected “Don’t Know” as a response to the target question.

Phonological Priming of TOT Resolution

TOT resolution, i.e., the percentage of target retrieval following correct TOT responses, was calculated for each priming condition, and the means and standard deviations are displayed

in Table 4. The mean proportion of TOT resolution was analyzed using a repeated measures ANOVA with Priming Condition (first phoneme prime, first syllable prime, unrelated control) as a factor and showed no significant main effect ($F < 1$).[1] Despite the non-significant main effect, pairwise comparisons were conducted between each priming condition and the unrelated control to test our specific hypotheses. While TOT resolution following the first phoneme prime did not differ from the control ($p = 0.612$), there was a marginally significant effect when comparing the first syllable and unrelated control ($p = .094$): TOT resolution following the first syllable prime was marginally higher than TOT resolution following the control (see Figure 7).

Table 4

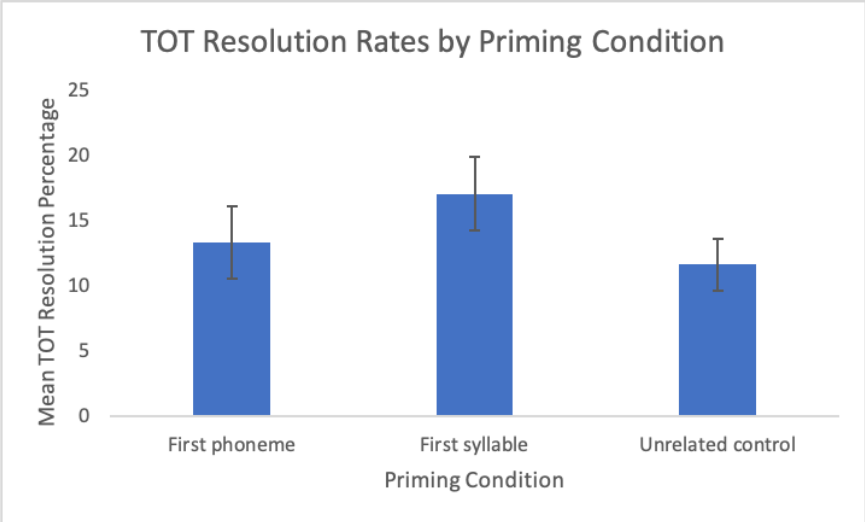
TOT Resolution Rates (Percent) for Each Priming Condition

Priming Condition	Mean Resolution	Standard Deviation
First phoneme	13.37	18.61
First syllable	17.12	18.73
Unrelated control	11.66	13.33

[1] The analysis conducted with all participants, including outliers, also showed a nonsignificant main effect ($F < 1$).

Figure 7

Percent of TOT Resolution as a Function of Priming Condition



Syllable Frequency

Additionally, we conducted analyses on whether the target's first syllable frequency influenced TOT incidence and resolution. We determined atonal syllable frequencies of the first syllable of each cheng-yu based on a corpus containing the 3,500 most frequent Chinese syllables (San, 2002). Atonal syllables were syllables independent of tone (e.g., "san"). Unlike the syllable frequencies used in Farrell and Abrams (2011), this corpus bases syllable frequencies on how often a syllable occurs in any position in a Mandarin word, rather than on how often a syllable occurs in a word's first position.

We used a median split to categorize targets' first syllables as higher- or lower-frequency. Atonal syllables were marked as "higher frequency" if they occurred more than 648,320 times in the corpus (which was the median syllable frequency of our targets) and marked as "lower frequency" if they occurred fewer times. The mean proportions of TOT incidence and resolution were calculated for each syllable frequency category. A paired-samples

t-test showed no significant difference ($t < 1$) in TOT incidence between targets with higher frequency first syllables ($M = 0.173$, $SD = .074$) and lower frequency first syllables ($M = .182$, $SD = .086$). A paired-samples t-test on TOT resolution for correct TOT responses likewise showed no significant effect ($t < 1$), as TOT resolution for targets with higher frequency first syllables ($M = .120$, $SD = .124$) was equivalent to targets with lower frequency first syllables ($M = .157$, $SD = .136$).

Tonal syllable frequency (syllables marked with tone, e.g., san1, san2, san3, or san4 for the syllable "san") was also used to categorized targets, and they were marked "higher frequency" if they occurred more than 155,921 times in the corpus (the median) and "lower frequency" if they occurred 155,921 times or below. A paired-samples t-test comparing tonal syllable frequency groups found no significant difference ($t < 1$) in TOT incidence between targets with higher frequency first syllables ($M = .180$, $SD = .076$) and targets with lower frequency first syllables ($M = .153$, $SD = .148$). There was also no difference in TOT resolution ($t < 1$) for targets with higher frequency first syllables ($M = .136$, $SD = .147$) and lower frequency first syllables ($M = .158$, $SD = .168$).

Partial Recall during TOT States

When asked to give partial information about their TOT states during the experiment, our participants only recalled characters, never individual phonemes. Participants' partial information included cheng-yus related to the target, incorrect/made-up cheng-yus, words with two or three characters, or single characters. We analyzed the mean proportion of times that participants recalled the first character of the target in a TOT state as compared to other characters within the target. Across all conditions, participants recalled the first character of a target ($M = .085$, $SD = .016$) significantly less ($p = 0.007$) than they recalled other characters

within the target cheng-yu ($M = 0.151$, $SD = .018$). A chi-square analysis showed that when participants did recall the first character of a target, they recalled it in significantly different positions within their answers (X^2 (5, $N = 54$) = 24.667, $p < 0.000$). Table 5 shows the distribution of all positions in which participants recalled the first character of the target, with participants most often recalling it in the first position (33%). It is worth noting that participants were more likely to recall the first character by itself or within a shorter word that was not a cheng-yu than they were to recall the first character in a non-first position in a related or made-up cheng-yu.

Furthermore, we wanted to see whether priming affected partial information recall. We analyzed whether priming the first syllable ($M = .086$, $SD = .200$) or first phoneme ($M = .093$, $SD = .155$) leads to more recall of the first character than priming the control word ($M = .077$, $SD = .121$) when participants remain in a TOT state, finding no significant effect ($t < 1$). We also found no significant effect ($t < 1$) for whether participants recall the first phoneme of a cheng-yu more frequently than other characters when primed with the first phoneme ($M = .085$, $SD = .141$) or first syllable ($M = .094$, $SD = .201$) than a control condition ($M = .076$, $SD = .129$).

Table 5

Distribution of First Character during Partial Information Recall

Recalled Position	Percentage
First character position within a cheng-yu	33%
Second character position within a cheng-yu	4%
Third character position within a cheng-yu	4%
Fourth character position within a cheng-yu	11%
Alone, without other characters	22%
Within a two- or three-character word	26%

Experiment 2

Methods[2]

Participants

60 native Mandarin speakers aged 18-28 (40 female, 19 male, 1 unspecified; $M = 21.2$ years, $SD = 2.5$; 54 right-handed, 2 left-handed, 4 ambidextrous) were recruited from the participant pool at Beijing Normal University and Chinese Academia of Science Institute of Psychology. All participants were students at universities in Beijing, who reported that their first and only native language, as well as their most dominant language, was Mandarin. All participants reported no health problems and normal to corrected eyesight. They were reimbursed monetarily (100 RMB ≈ $15) for their participation upon the completion of the experiment.

As in Experiment 1, participants were asked to fill out a subset of the Mandarin version of the LEAP-Q to assess the extent to which they were bilingual or multilingual. The LEAP-Q showed that all participants self-identified as either bilingual or trilingual (see Table 6). Besides Mandarin and English, trilingual participants also reported learning Russian, French, Korean, and Japanese, although they rarely communicated in these languages in daily life and did not have native-like fluency. All claimed that they learned English as their second language, but when asked to rate their proficiency in reading, comprehension, and speaking in English, they did not rate themselves to be highly proficient (see Table 7). Most also reported that they were exposed to their native language of Mandarin more frequently than any other languages (see Table 8).

[2] The methods section for Experiment 2 was written by PengBo Hu, based off of the methods section for Experiment 1.

Table 6

Number of Languages that Participants Learned in Experiment 2

Number of Languages Learned	Number of Participants
2	50
3	10

Table 7

Participants' Self-Rated English Proficiencies in Experiment 2

Self-Rated English Proficiency	Mean	Standard Deviation
Speaking proficiency	4.22	1.52
Comprehension proficiency	4.92	1.84
Reading proficiency	5.98	1.66

Note. 1 indicates not being proficient and 10 indicates being most proficient.

Table 8

Participants' Exposure to Mandarin in Everyday Life in Experiment 2

Percentage of Time Exposed to Mandarin	Number of Participants
60-70%	11
70-80%	10
80-90%	18
90-100%	21

Materials

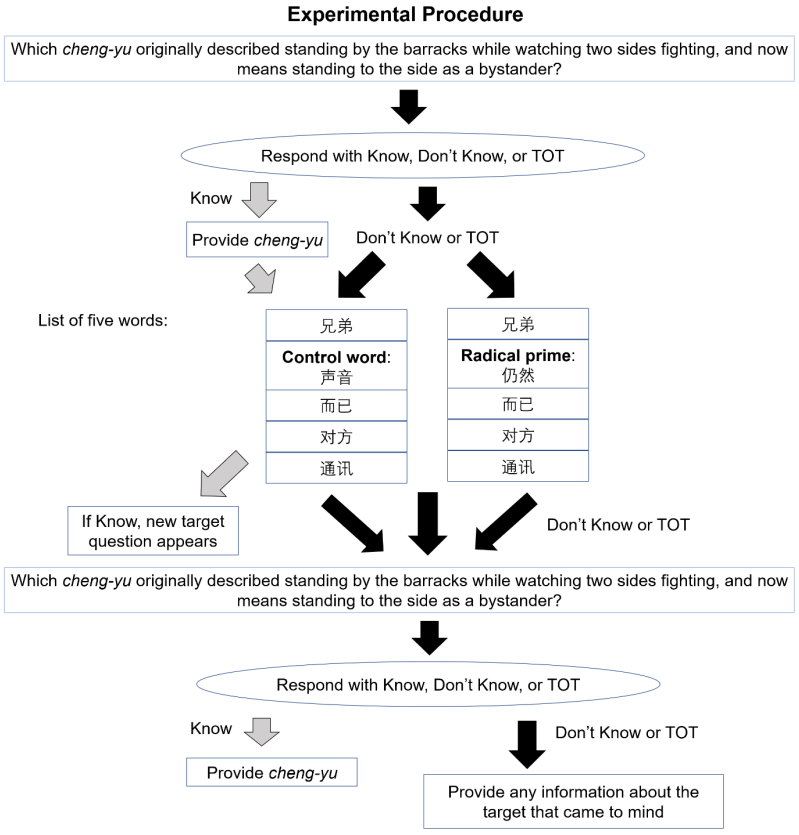
The same 100 cheng-yu targets, unrelated control words, filler words, and target questions from Experiment 1 were used in this experiment. Each target was assigned a two-character prime word that shared the semantic radical with the first character of the target word (e.g., 仍然reng2ran2, for the target 作壁上观; note that the left component of 仍 is identical to the left component of 作, the first character of the target). The radical primes are displayed in Appendix C. Participants completed the same pre- and post-experiment questionnaires and multiple-choice recognition test as in Experiment 1.

Design and Procedure

The experiment included one within-participants factor: priming condition (radical primes and unrelated control words). The procedure of Experiment 2 (see Figure 8) was the same as that in Experiment 1, except that the second word in the list of five words—presented after participants responded to each target question—was either a radical prime or a control (see Figure 8). The computer program randomly selected between the two conditions, with the constraint that both conditions were selected before repeating one of them.

Figure 8

Diagram of the Experimental Procedure for Experiment 2



Note. In the list of five words, the bold label indicating the second word in the list is shown here for clarity but was not shown during the actual procedure.

Results

We excluded three participants from analyses due to accidental early termination of the computer program, and we analyzed the remaining 57 participants' responses to the post-experimental questionnaire to determine whether participants were aware of or intentionally used primes to retrieve the target cheng-yu. The majority of participants (81%) did not notice a relation between the prime words and the target questions, and 11 participants (19%) guessed an incorrect relation between the prime word and the target questions (e.g., they were synonyms or

semantically related to the cheng-yu). Four participants who did not have at least two TOTs in each of the two priming conditions (i.e., less than four TOTs) were considered outliers and excluded from subsequent analyses. Participants' initial responses were categorized and revealed a distribution similar to Experiment 1: correct "Know" responses (23%), incorrect "Know" responses (16%), correct "TOT" responses (20%), incorrect "TOT" responses (5%), and "Don't Know" (36%) responses.

Orthographic Priming of TOT Resolution

Mean TOT resolution of correct TOT responses was calculated for TOTs followed by radical primes vs. control words. A paired-samples t-test showed no significant difference ($t < 1$) in proportion of TOT resolution following radical primes ($M = .159$, $SD = .150$) and control words ($M = .165$, $SD = .187$).

Radical Frequency

A median split was used to categorize the radicals of the targets' first character as higher- or lower- frequency. Radical frequencies were taken from Xun et al. (2016), which found the percentage of occurrences of each radical based on the *People's Daily* Corpus (人民日报语料库). Radicals were grouped as "higher frequency" if they had a frequency above 0.008629 (the median frequency of our radicals) and "lower frequency" if their frequencies were lower. To assess whether a target's first radical frequency affected TOT resolution, a paired-samples t-test was conducted and revealed a significant difference ($t(51) = 2.058$, $SEM = 0.030$, $p < .045$), where TOTs for targets with higher frequency radical primes were more likely to be resolved ($M = .206$, $SD = .227$) than targets with lower frequency radical primes ($M = .144$, $SD = .128$). A paired-samples t-test was also conducted on TOT incidence, which was significant ($t(52) = -5.041$, $SEM = 0.010$, $p < .001$). Targets with higher frequency radicals resulted in fewer TOTs

(M = .170, SD = .107) than targets with lower frequency radicals (M = .218, SD = .129). See Figure 9 for TOT resolution and incidence based on radical frequency.

Figure 9

Percent of TOT Incidence as a Function of Priming Condition

Partial Recall during TOT States

We wanted to see whether partial recall and recall of the first character in Experiment 2 were similar to Experiment 1. As with Experiment 1, participants only reported recalling characters when prompted for partial information and never individual phonemes. Additionally, a chi-square analysis showed that participants recalled the first character of a target in marginally significantly different positions within their answers (X^2 (5, N = 51) = 9.588, p < 0.088). Table 9 shows the distribution of the positions in which participants recalled the target's first character. Similar to Experiment 1, participants recalled the first character in the cheng-yu's first character position most frequently. Moreover, they recalled the first character by itself or with a shorter

word that was not a cheng-yu more frequently than they recalled the first character in an incorrect position within the cheng-yu.

Table 9

Distribution of First Character during Partial Information Recall

Recalled Position	Percentage
First character position within a cheng-yu	31%
Second character position within a cheng-yu	8%
Third character position within a cheng-yu	14%
Fourth character position within a cheng-yu	14%
Alone, without other characters	17%
Within a two- or three-character word that was not a cheng-yu	16%

General Discussion

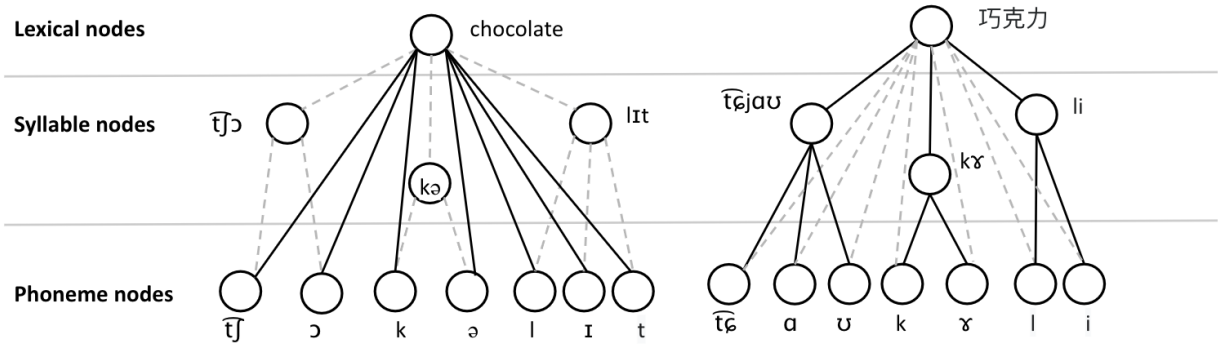
Experiments 1 and 2 enabled us to study the experience of the TOT phenomenon in Mandarin, which revealed some major differences between TOT states for Mandarin and English speakers. Phonological and orthographic information independently affected TOT resolution, albeit in different ways. Specifically, a first syllable prime increased TOT resolution whereas a first radical prime did not, demonstrating phonological influences. First radical frequency increased TOT resolution and decreased TOT incidence whereas syllable frequency did not, demonstrating orthographic influences. These results will be interpreted within a new model of Mandarin TOTs, modified from MacKay and Abrams (1998)'s English node structure model.

Experiment 1 examined how phonological priming affects TOT states in Mandarin using primes that contained either the first phoneme or the first syllable of the target. Relative to unrelated control words, there was no evidence of first phoneme priming on TOT resolution, but

there were marginally higher TOT resolution rates following first syllable primes. Our findings regarding phonological effects on TOT resolution in Mandarin can be contextualized with O'Seaghdha (2010)'s notion of the proximate unit, the idea that different languages have different units that are first retrieved during speech production. O'Seaghdha (2010) proposed that the proximate unit in Mandarin is the syllable, as evidenced by a variety of speech error (Chen, 2000), ERP (Feng et al., 2019), and behavioral research studies (Chen et al., 2002; Chen & Chen, 2013; O'Seaghdha et al., 2010), all of which indicate that Mandarin syllables facilitate and function as independent units during speech production. In contrast, studies in English show that the phoneme facilitates speech production, suggesting that the English proximate unit is the phoneme (Damian & Dumay, 2009; Levelt et al., 1999; Meyer, 1990, 1991; Schiller, 2000). Although O'Seaghdha (2010) does not explicitly draw upon node structure models, the proximate units can be embedded within these models to represent the different phonological systems of Mandarin and English. In such a model (see Figure 10), when successful language production in a general question task occurs, lexical items activate all connected proximate units. Specifically, a lexical item should activate all syllable nodes in Mandarin and all phoneme nodes in English, allowing participants to fully retrieve a word. However, in TOT states, the lexical item might not activate—or only partially activate—the proximate units. Our hypothesis is that the degree to which phonological priming will affect TOT resolution can be explained by the number and strength of connections to the initial proximate units.

Figure 10

The proximate unit theory for English (left) and Mandarin (right)



Note. Solid lines show the default connections that are activated during speech production, based on each language's proximate unit. Dotted lines show connections which exist but are not activated unless a specific task requires shifting to these connections.

Figure 10 displays the node structure model for the word *chocolate* in English vs. in Mandarin. Both languages have syllable and phoneme nodes, but the connections between the lexical node and syllable nodes in Mandarin are stronger than the connections with the phoneme nodes because the syllable is the proximate unit. Conversely, in English with the proximate unit as a phoneme, connections between the lexical node and phoneme nodes will be the strongest. In this node structure model, priming TOT resolution with a syllable activates a different number of proximate units in the two languages: providing a Mandarin syllable will activate one syllable proximate unit, whereas providing an English syllable activates multiple phonemes or proximate units. This difference explains why, in contrast to studies showing that first syllable primes significantly facilitate English TOT resolution (Abrams et al., 2003), the first syllable priming effect in Mandarin in the present study was smaller. For example, when priming the first syllable of the Mandarin word 巧克力 (*chocolate*), the syllable node /t͡ɕjɑʊ/ is activated. Mandarin syllables are characterized by having several homophones, typically four to 40 homophones,

which can be combined with various other characters to form words (Zhou & Marslen-Wilson, 1995). Each homophone can be paired with anywhere from a couple to hundreds of other characters to form new lexical items (Pleco, Inc.). Thus, a syllable node like /t͡ɕjɑʊ/ connects to potentially hundreds of lexical nodes that can contain any of its homophones. Priming that syllable node sends activation to all of these lexical nodes, which lessens the likelihood of sending sufficient activation to the target's nodes and decreases the priming effect. However, this dilution does not completely negate the priming effect: because Mandarin only has about 400 syllables in total, this constraint limits the number of possible node connections to which activation may spread. Thus, a Mandarin syllable node has enough (but not too many) node connections to diminish the priming effect but still allow it to occur.

This process results in fewer instances of TOT resolution than is seen in a language like English. In English, priming the first syllable of "chocolate" activates the phoneme nodes /t͡ʃ/ and /ɔ/, and the activation from the multiple phonemes converges on lexical nodes that contain all these phonemes. There are fewer words in English that begin with that pattern of phonemes, so the target is able to accumulate enough activation for successful word retrieval. Based on the model in Figure 1, syllable nodes may not play a major role in English TOT resolution; the syllable nodes exist and can be accessed during specific tasks, but the phoneme nodes spread the activation that is ultimately responsible for lexical retrieval. Furthermore, priming just one phoneme (one proximate unit) does not affect English TOT resolution because one phoneme diffuses activation onto many other lexical nodes. For example, there are almost 75,000 English words that begin with the commonly occurring letter "s" ("Lots of Words"). The sheer number of lexical items connected to one phoneme node decreases the likelihood that the target will accumulate the most activation and resolve TOTs (Abrams et al., 2003). Thus, Mandarin

speakers may similarly need to be primed with multiple proximate units (syllables) in order to effectively resolve TOT states. Another consideration is the amount of overlap between the prime and target. Perhaps the marginal first syllable priming effect in Mandarin also reflects the fact that we primed a smaller proportion of target words in Mandarin (i.e., one Mandarin syllable primed 1/4 of a four-syllable target) relative to studies using first syllable priming during TOTs in English which often used two-, three-, and four-syllable targets (Abrams et al., 2003; Farrell & Abrams, 2011; James & Burke, 2000).

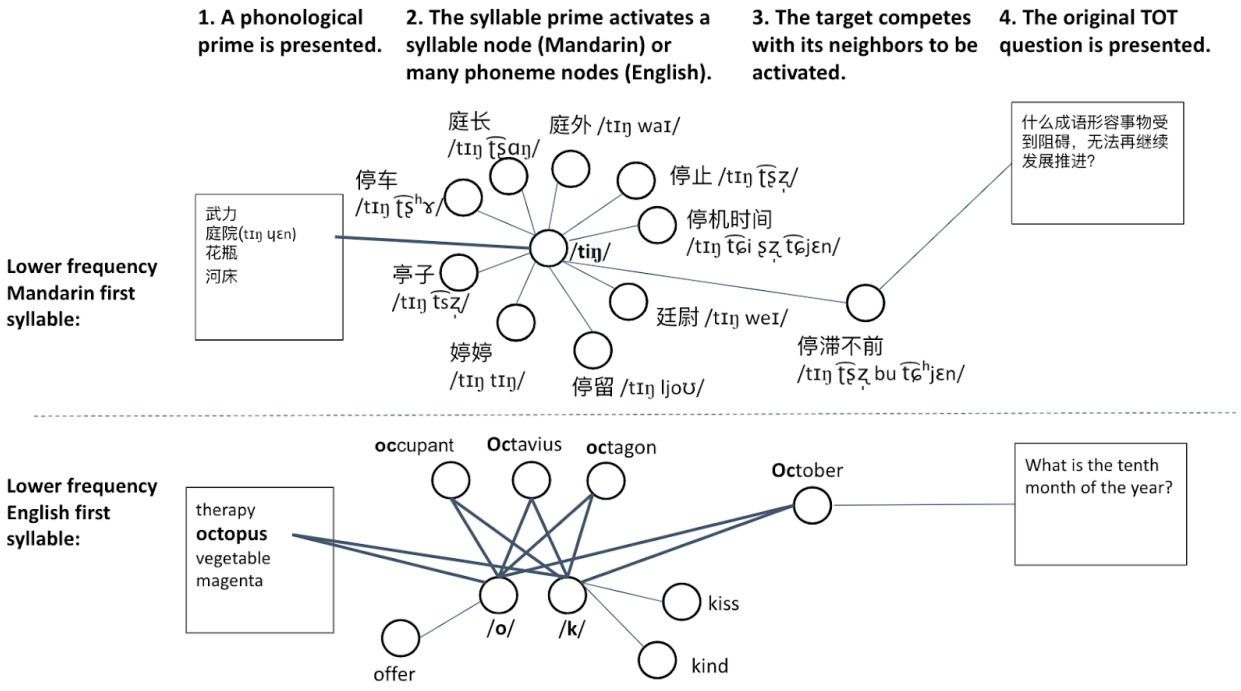
Despite the importance of the syllable as the Mandarin proximate unit, we did not find any first syllable frequency effect for TOT incidence or resolution for either atonal or tonal syllable frequencies. Specifically, TOT incidence and resolution were similar regardless of whether the target had a higher or lower frequency first syllable. This lack of a syllable frequency effect can be explained by the number of node connections that Mandarin syllables have. So far, we have established that Mandarin syllables are unique in that they have many homophones; a slightly different but critical point to note is *all* Mandarin syllables have homophones. Every syllable in Mandarin—lower frequency or higher frequency—has many homophones and therefore connects to several lexical nodes. So, syllable priming is always diffused and, as we have previously shown, only has a small effect on TOT resolution. A higher or lower syllable frequency does not significantly impact TOT incidence or resolution in different ways, because there may not be as much of a difference between the number of nodes connected to higher or lower frequency syllable nodes.

Our findings of no first syllable frequency effect on the incidence of Mandarin TOTs are consistent with Farrell and Abrams (2011), who found that young English speakers showed no difference in TOT incidence between targets with higher frequency and lower frequency first

syllables. However, they did find a syllable frequency effect on TOT resolution, where English speakers who were primed with the first syllable of words resolved more TOTs for targets with lower frequency syllables. Farrell and Abrams (2011) proposed that a higher frequency first syllable node activates a greater set of lexical nodes such that priming is diffused, leading to fewer instances of TOT resolution. Our modified node structure model (see Figure 11) illustrates why TOT resolution in Mandarin may be affected differently by first syllable frequency from English. The proximate unit plays a key role because it determines the phonological unit that is first activated during speech production. The properties of this unit, such as the number of lexical units connected to it, ultimately determines the strength of a priming or frequency effect. During phonological priming in English, a lower frequency first syllable /ok/ given in the word "octopus" primes the phoneme nodes /o/ and /k/. There are words beginning with /o/ and /k/, but the combined priming of both phonemes converges on only a few lexical items such as "occupant" and "Octavius". The target "October" therefore does not need to compete with many other lexical nodes for activation and can be easily retrieved. Meanwhile in Mandarin, the word 庭院 (ting2yuan4) primes the lower frequency syllable node /tɪŋ/. Although the syllable /tɪŋ/ is lower frequency, it still connects to many lexical nodes—not just words containing the character 庭 (e.g. 庭长 /tɪŋ ʈ͡ʂɑŋ/ and 庭外 /tɪŋ waɪ/) but also various words containing its homophones (e.g. 停止 /tɪŋ ʈ͡ʂɻ̩/, 廷尉 /tɪŋ weɪ/, 亭子 /tɪŋ ʈ͡sɻ̩/, 婷婷 /tɪŋ tɪŋ/). Because all Mandarin syllables have homophones and a great deal of lexical connections, priming is strongly diminished regardless of syllable frequency and does not display a strong effect on TOT resolution.

Figure 11

The proximate unit theory for Mandarin (top) and English (bottom) during a lexical retrieval task in which the target word has a lower frequency first syllable



Note. The Mandarin syllable prime activates the proximate unit of a syllable node, which is used in several different words and also has many homophones. Meanwhile, the English syllable prime activates multiple phoneme nodes, whose priming converges on a small set of lexical items that contain both phonemes. Thicker lines indicate a stronger priming effect on lexical nodes, caused by the convergence of priming from multiple phoneme nodes.

Beyond first syllable priming and syllable frequency effects, our experiment brings up new insights and questions about the Mandarin syllable unit itself. With respect to partial information recall during TOTs, English speakers often recall the first phonemes of words during TOT states but rarely whole syllables (Abrams et al., 2003; Brown, 1991; Ecke, 1996). They can retrieve one proximate unit but not all of them, which makes retrieving the entire first syllable unlikely. However, participants in Mandarin TOT states never reported recalling individual

phonemes or parts of syllables in both of the present experiments. Rather, they always recalled one or more ***characters***, which were often the same first character as the target rather than simply a homophone of the first character.[3] This finding suggests that syllables are the most easily or most quickly accessible unit of information for participants when trapped in a TOT state, consistent with the syllable being the proximate unit. Additionally, recalling the syllable specific to the target, i.e., its first character, suggests that phonology and orthography are both activated during Mandarin TOTs, consistent with prior research on Mandarin speech production (Ouyang et al., 2020), and that priming a syllable node also automatically primes its orthography. A limitation of these conclusions is that our findings could have been affected by our experimental set-up, as participants typed in answers using a pinyin system that is typically used to type characters rather than individual phonemes. If we had explicitly asked participants to report any letters of pinyin that they could remember, we might have found more instances of phoneme recall. Additionally, because the pinyin system uses character recognition rather than recall (typing pinyin shows a list of possible characters to choose from), we cannot conclusively say that participants recalled the orthography of the first character of the target based on their partial information during TOT states. Nonetheless, the fact that all participants reported recalling characters in TOT states—and none reported recalling phonemes—is evidence that syllables play an important role for speech production in Mandarin.

Moreover, the order of syllable recall and movements between syllable positions have more flexibility in Mandarin language production compared to English, evidenced by

[3] It is worth noting that this finding was independent of priming. We also examined whether participants could better recall the first character of a target when given a syllable prime. Even if a syllable prime could not drastically facilitate retrieval of the entire word, it might still provide a boost for one syllable. However, our study did not find this effect, which is likely due to the small amount of data that was available to be analyzed. Only 18% of all responses were correct TOTs, and participants did not provide partial information for every TOT state that they had.

participants' recall during TOT states. They overall recalled the first character of a cheng-yu less frequently than other characters within the cheng-yu. When participants did recall the first character of a Mandarin target, they recalled the character in significantly different positions within their answers, a result that mirrors Chen (2000)'s study showing that entire syllables in Mandarin can move during speech errors. These findings are at odds with English speakers, who tend to recall the first phoneme of a word during TOT states rather than phonemes in the middle of the word. Furthermore, it seemingly contradicts the left-to-right principle of node structure theory (MacKay, 1987), which emphasizes the importance of the first syllable in activating an entire lexical item and provides a basis for why first-syllable priming is more effective than middle- or last-syllable priming, at least in English (Abrams et al., 2003).

However, nuances within our findings suggest an alternative explanation. Although participants retrieved the first character in significantly different positions, participants retrieved the first character most frequently (approximately half the time) in the first position or by itself. This detail suggests that syllables are still associated with positional information during Mandarin language production, even if it is easier for them to shift positions. Thus, we propose that the first syllable in Mandarin still retains importance as in English, although the morphosyllabic structure of Mandarin allows for greater flexibility in syllable movement in speech production. Moreover, the left-to-right principle can actually explain why participants recall the first character of a cheng-yu less frequently than others in TOT states. Assuming that the first syllable is critical in facilitating Mandarin lexical retrieval, participants who remember the first syllable are more likely to retrieve the entire word, resulting in fewer TOT states. In other words, when participants are in TOT states, a likely cause is because they do not have access to the first syllable, which causes them to enter the TOT state in the first place and thus

not be able to retrieve the first syllable during the TOT. However, if the first syllable and its position are still important in speech production, how can Mandarin speakers frequently recall non-first syllables during TOT states and switch the first syllable into different positions? These findings may stem from Mandarin's unique structure where each syllable is a self-contained unit of meaning and contributes to the overall meaning of the word (e.g. "自行车" (*bicycle*), where "自" means *self*, "行" means *travel*, and "车" means *vehicle*). Additionally, Mandarin syllables do not easily resyllabify (Chen et al., 2002), which may make switching syllables cleaner and easier. Thus, retrieval of a Mandarin syllable may not be as dependent on the order of syllables within a word, and because each syllable plays a role in constructing the meaning of the target, it may be more salient to recall. In contrast, a word's meaning in English is entirely dependent on the order of syllables, e.g., switching the syllables of the word "bicycle" turns the word into a non-meaningful unit like "cybicle", and speakers rarely make errors like this (Dell, 1986; Levelt, 1989; Shattuck-Hufnagel, 1979).

Future studies might explore how semantic and phonological systems interact to influence syllable movements during TOT states and whether the self-contained meaning of a syllable allows it to move more independently during recall. In fact, English TOT studies using names as targets may offer some support for this claim. In an unpublished study by Abrams which studied name retrieval in English (L. Abrams, personal communication, October 30, 2020), participants were sometimes asked to retrieve proper names composed of two first names (e.g., "John" is a last name in "Elton John", but often appears as a person's first name). Participants who were stuck in TOT states sometimes swapped the first and last names during partial recall (e.g., they reported that the first name was John). However, participants did not switch names for targets such as "George Clooney" where "Clooney" is not an acceptable first

name. Unlike non-names, conventional English first names can be seen as having independent meanings because they can stand on their own without other syllables and have an immediate semantic association (e.g. it is commonly accepted in English that “George” is a usually a name for a man), allowing them to parallel the morphemic nature of Mandarin syllables. Such switches in English suggest that syllables with individual meanings are encoded with position to some extent, but not to the same strict point as expected of typical, English non-names. Thus, it is possible that across languages, syllables’ positional flexibility is greater if syllables are self-contained in their meaning. More flexible syllable encoding in Mandarin may also partially explain the weaker first syllable priming found in Experiment 1. If left-to-right activation generally holds but is less stringent in Mandarin, priming the first syllable may not facilitate left-to-right activation as smoothly as in English, which will lessen the chance of successful lexical retrieval. This explanation would also account for why White, Abrams, and Frame (2013) found that priming English proper names via first syllable is not as effective as priming non-names, as the positions of syllables of English names may not be as strictly encoded given the general flexibility and creativeness involved in naming. The study found only marginal priming from the first syllable of a proper name, with the priming effect only becoming significant when the entire first name was primed. As of now, node structure theory does not account for this variance in syllable retrieval based on morphemic value, but future studies could study this distinction more thoroughly, perhaps by creating a more detailed node system for semantics that interacts with phonological nodes.

Because much of our hypotheses are based on the idea of the proximate unit, future studies in Mandarin and English can study more definitively whether priming activates syllable nodes in Mandarin and phoneme nodes in English. For example, TOT studies in Mandarin could

use primes with more than one syllable to see if providing multiple syllable proximate units and/or a greater proportion of the target's phonology will boost TOT resolution significantly. One could even prime a syllable that is not the first syllable in Mandarin to see if there is still a priming effect given that Mandarin's left-to-right activation seems less rigid than in English. On the other hand, to see if the proximate unit in English is indeed the phoneme and not the syllable, we could use targets whose first syllables are three or more phonemes and then prime either with two phonemes, which are multiple proximate units but not an entire syllable. If the two phonemes are able to prime TOT resolution, this result would be evidence for the theory of the proximate unit.

While Experiment 1 investigated phonological priming, Experiment 2 investigated how orthographic priming affects TOT states in Mandarin. Most TOT studies have not examined the role of orthography in TOT incidence and resolution, especially because alphabetic languages such as English often conflate orthography and phonology. For instance, in English the letter "b" is always associated with the sound /b/, and this direct mapping of orthographic letters to their pronunciation is true for many other letters. However, Mandarin enables us to separately test phonology and orthography's influence on TOTs, as most Mandarin characters do not provide information about their pronunciation. For example, none of the characters for the Mandarin word for *bicycle*, 三轮车 san1lun2che1, orthographically convey how they sound. Following orthographic primes with a character sharing the target's first radical, there was no priming effect on Mandarin TOT resolution relative to an unrelated control word. This result is consistent with the idea that phonology, not orthography, is the primary cause of Mandarin TOTs, similar to English TOTs which are thought to result from an inability to access a word's entire phonology (MacKay & Burke, 1990). However, this conclusion is limited by the fact that our primes may

have had an insufficient amount of orthographic overlap to prime retrieval of the target; one radical may not transmit sufficient activation to the target. Future research could use orthographic primes that provide more information about the target, e.g., characters with little phonological overlap that look similar (i.e. 关 guan1 vs. 天 tian1). Although radical primes did not show a priming effect on TOT resolution, orthography in terms of radical frequency did influence TOT incidence and resolution. TOT states occurred significantly less frequently and were resolved more frequently for cheng-yus beginning with higher frequency radicals than lower frequency radicals. This is consistent with past literature demonstrating that priming Mandarin radicals can affect language production when the task at hand does not require word-pair learning (Qu & Damian, 2019; Zhang et al., 2009; Zhao et al., 2012).

We propose a revised node structure model (see Figure 12) to account for the above findings on Mandarin TOTs. A critical component not previously suggested for TOTs is the orthographic system's interactions with the phonological system, which are particularly relevant for a language like Mandarin where phonology and orthography are not predictive from each other. As shown in Figure 12, radicals from the orthographic system connect to several different phonological, orthographic, and lexical nodes, creating an intricate web of connections that closely ties together various systems of language production. In this example, the lexical term to be retrieved is 巧克力 quao3ke1li4, meaning *chocolate*. In (a), this lexical item has been primed with the left radical of the first character, 工. In (b), after 工 is primed, activation spreads from 工 to many other nodes: stroke nodes, the character node 巧, the lexical node 工 (*work*), and the phonological nodes /t͡ɕjɑʊ/, /*goŋ*/, /t͡swɔ/, and /*goŋ*/, to name a few. Notably, the radicals used in our study as primes do not provide phonetic information, so the lexical nodes to which they connect have different pronunciations (i.e., are not phonological neighbors) from the target

syllable nodes. Within this model, the lack of a radical priming effect can be explained by the interaction between the two systems. Mandarin characters with the same radical can have different pronunciations so that priming a radical also primes several syllable nodes different from the target. Therefore, any activation being sent to the target from the orthographic system is lessened when passed to the phonological system, which results in no effect on TOT resolution. However, the frequency of radicals can impact TOT incidence and resolution independently of being primed within our model. Figure 12 (c) shows that nodes continue to spread activation until the syllable nodes of 巧克力 are retrieved. The character node 巧 primes the lexical item 巧克力, which then primes its syllable nodes. At the same time, there may be many other indirect connections between the lexical node 工 (*work*) and the target lexical item 巧克力. For example, the lexical node 工 (*work*) might prime an associated lexical node 力 (*strength*), which then primes the lexical node 巧克力 because 力 is its third character, which then primes syllable nodes. Although this example is very specific to 巧克力, the morphosyllabic nature of Mandarin in general creates many associations between different radicals and lexical nodes which can facilitate activation.[4]

Radical frequency becomes relevant in TOT resolution and incidence because it can influence the strength of connections from the radical node. For TOT resolution, a higher frequency radical means that the radical node's connections to the correct phonological nodes are activated more frequently and are stronger, by virtue of this radical being used more often in the

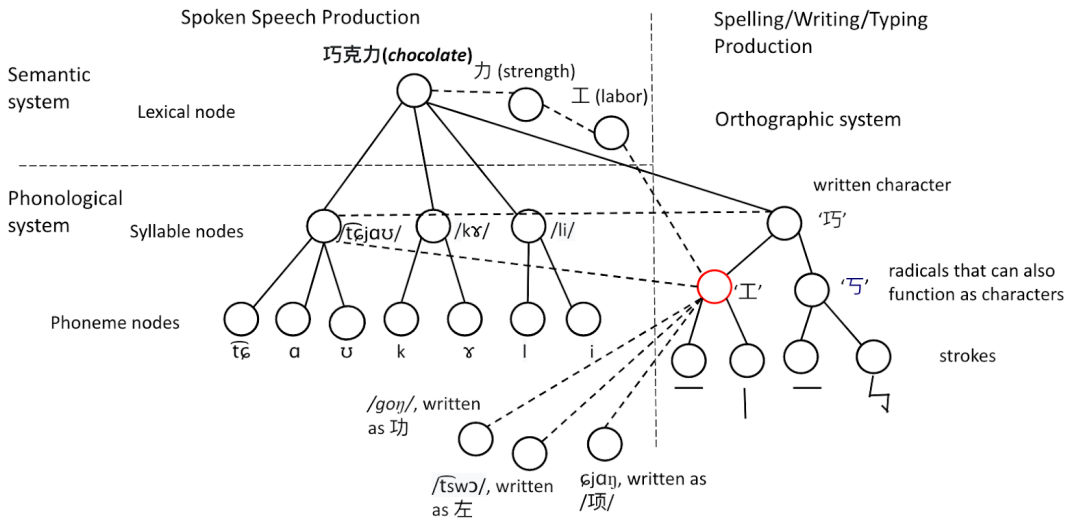
[4] Our node structure model can explain why Ouyang et al. (2020) found that older participants experienced fewer TOTs when they were first exposed to a prime with the same character (same orthography and phonology) as a target celebrity's name, compared to a prime that shared just the same phonology but not orthography of the first character. Priming a character from a target celebrity's name sends activation to both the phonological and orthographic nodes. Phonological priming helps with the retrieval of phonological nodes; meanwhile, the orthographic nodes can collectively transmit activation to phonological nodes, providing extra activation to them. Future studies could examine if giving both the phonology and orthography of a character as a prime affects TOT incidence and resolution. Based on Ouyang et al. (2020)'s results, one may see a double effect, where phonological and orthographic primes together create a greater priming effect.

context of other words. Therefore, when activation spreads between nodes, it occurs along well-traveled paths that enable activation to spread more efficiently rather than being watered down until the lexical item is properly retrieved. Activation from the radical may decrease as it passes through different nodes to get to the correct phonological nodes, but because there is a highly interconnected system in which multiple nodes can be triggered by a single radical node, the nodes can collectively trigger the necessary phonological nodes for lexical retrieval. Essentially, a higher frequency radical can result in more instances of TOT resolution because its multiple connections to phonological nodes are stronger and allow for more efficient activation. Conversely, a higher frequency radical leads to less TOT incidence because connections between nodes are stronger, resulting in fewer retrieval failures. Over a person's lifetime, as radicals help to activate phonological nodes, there will be a considerable difference in the amount of activation that higher frequency radicals give to phonological nodes compared to lower frequency radicals. Phonological nodes connected to lower frequency radicals will be activated less frequently and will have weaker connections in general when compared to phonological nodes connected to higher frequency radicals, making lower frequency radicals more susceptible to TOT states.

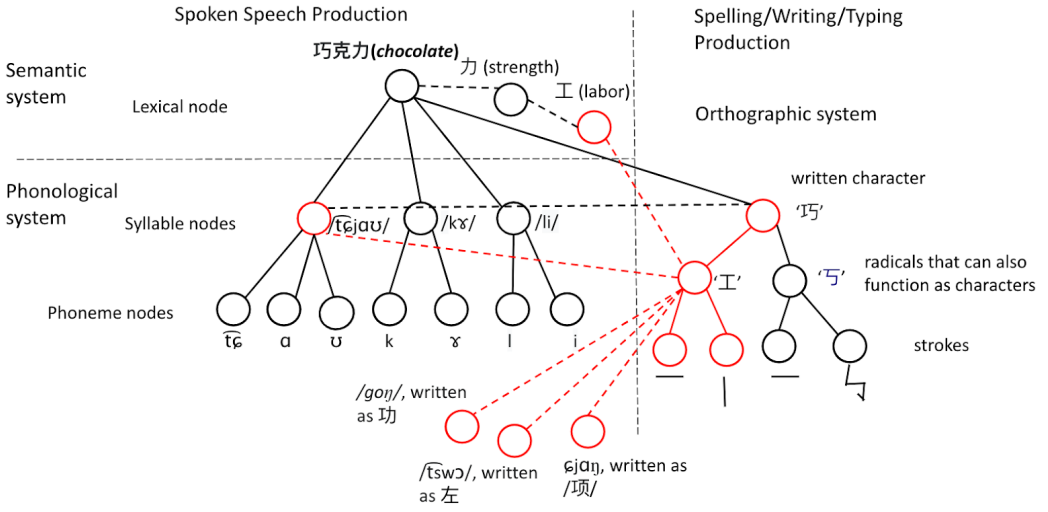
Figure 12

Timeline of radical priming for the lexical node 巧克力, meaning 'chocolate', in influencing TOT resolution

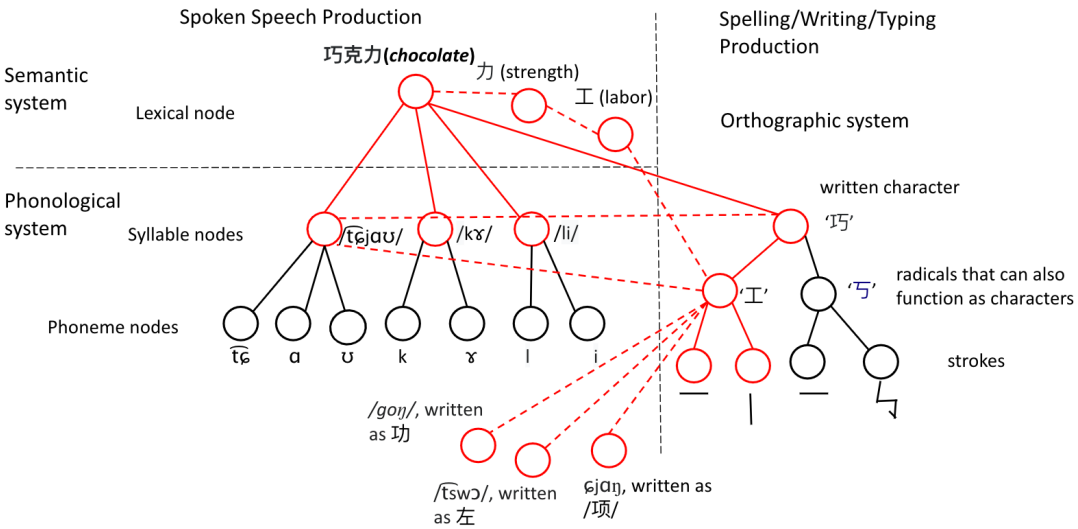
(a):



(b):



(c):



Note. Dashed lines represent the diluted activation stemming from radical nodes to non-orthographic nodes. Red lines present connections that have been activated. In (a), a given radical prime is able to prime the radical node "工". In (b), the radical node immediately spreads priming to orthographic, phonological, and lexical nodes. In (c), these other nodes go on to prime even more phonological and lexical nodes. Ultimately, the collective priming converges on the phonological nodes that correspond with the target lexical node, allowing for successful word retrieval. Higher frequency would decrease the possibility of TOT incidence and increase the possibility of TOT resolution by increasing the number and strength of connections to other nodes.

Conclusion

By utilizing the opacity of phonology and orthography in Mandarin, Experiments 1 and 2 demonstrated that both phonological and orthographic systems influence the TOT state for Mandarin speakers. First syllable phonology but not orthography caused a marginal facilitation effect for TOT resolution, while radical (orthographic) frequency but not syllable frequency led to lower rates of TOT incidence and higher rates of TOT resolution. Overall, the experiments demonstrate that Mandarin and English speakers experience TOTs with key similarities and differences. In terms of similarities, TOTs are—in part—a phonological phenomenon in both languages, as TOT resolution can be facilitated by providing participants with phonological cues. Moreover, the first units of lexical items generate priming effects for TOT resolution, suggesting that they play an important role in speech production for left-to-right languages, despite vastly different linguistic and writing systems. On the other hand, our experiments reveal differences between TOTs in Mandarin and English which warrant further investigation. Notably, Mandarin speakers in TOT states frequently recall syllables rather than phonemes and in different positions than are found within the targets, likely because of Mandarin's morphosyllabic nature. This

finding poses the question of whether syllables across languages can behave differently based on the amount of self-contained meaning that they have.

Moreover, the orthographic system of Mandarin plays a role in TOT production, a previously undocumented phenomenon. Other models have explored the relationship between phonology and orthography in English (MacKay & Abrams, 1998) and illustrated how language production might work in Mandarin (O'Seaghdha, 2015). Our node structure model for Mandarin posits a method of interaction between orthographic and phonological systems that is consistent with previous models but provides a better understanding of how TOTs specifically work. While the general conclusion is that radicals can exert influences on language production through a web of multi-system connections, future studies might examine how radicals connect to other nodes in closer detail and whether, as with syllable neighborhoods in English, one can map out radical neighborhoods that more accurately account for the plethora of connections attached to the Mandarin orthographic system. Our findings in terms of a radical frequency effect also raise the issue of whether past TOT studies in English are confounded by simultaneous phonological and orthographic overlap. Such overlap could be increasing the likelihood that priming occurs, since the priming is driven by both the phonological and orthographic systems. Future TOT studies in English could use homophones of certain syllables (e.g., "cinnamon" and "synthesize" share the /sɪn/ sound but mostly different orthography) to see if these primes still facilitate TOT resolution to the same extent as primes with both orthographic and phonological overlap.

Not only does our study highlight the need to examine TOTs in languages with various linguistic and writing structures, but by studying the universal and language-specific components of TOTs, we may develop a better understanding of how language production systems work in

general. In our experiments, we attribute many of the differences in Mandarin and English TOTs to O'Seaghdha (2010)'s theory of the proximate unit. This concept effectively explains why syllable priming in Mandarin works less effectively than in English and why participants frequently recalled characters instead of phonemes during TOT states. However, the concept of the proximate unit can be further studied to see how it affects a wide range of language production systems. Mandarin's linguistic and writing systems clearly place an emphasis on syllables, but in other languages, the distinction may not be as clear. For example, for syllable-timed alphabetic languages such as Spanish, would the proximate unit be a phoneme or a syllable? As with our experiment, one might use TOT experiments with phoneme and syllable primes in order to examine this question. Ultimately, our experiments not only document TOTs in Mandarin but raise several questions about past work with English TOTs and future work with the proximate unit.

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Appendix A

Cheng-yu Targets and Corresponding Questions

Cheng-yu Target	Original target question	Translated target question
仗义疏财	什么成语形容一个人重视友谊，在危难的时候愿意拿出自己的钱来帮助别人?	What cheng-yu describes a person who values friendship and is willing to spend their own money to help others in times of crisis?
假公济私	什么成语用来形容用集体的名义，谋取个人的利益?	What cheng-yu is used to describe the use of a collective name to seek personal benefits?
停滞不前	什么成语形容事物受到阻碍，无法再继续发展推进?	What cheng-yu describes things that are hindered and cannot continue to develop?
借题发挥	什么成语指某人趁着谈论另一事或者靠某件事情来做文章，而说出自己心中的真实意图，或者表达一些与之无关的言论?	What cheng-yu means discussing one topic but expanding the topic to reveal your true intentions, or trying to say something irrelevant?
俨乎其然	什么成语形容人摆出一副十分严肃正经的样子，常常有讽刺意味?	What cheng-yu is used to describe a person posing a very serious but often ironic appearance?
俯首帖耳	什么成语原意狗见了主人那样低着头，形容卑屈驯服的样子?	What cheng-yu originally described how a dog bows its head when seeing its owner, to describe a subdued appearance?
倒行逆施	什么成语原来指办事违反常理，不择手段，现在多用来比喻所作所为违背时代的潮流或人民的意愿?	What cheng-yu originally meant to do unscrupulous things against common sense, but now is often used as a metaphor for actions that go against the trend of the times or the will of the people?
偃旗息鼓	什么成语原指行军时隐蔽行踪，不让敌人觉察，现比喻事情终止或声势减弱?	What cheng-yu describes an army that matches unnoticed, which now means that something has ended or diminished?
伤风败俗	什么成语多用来谴责对社会道德有损害和不良影响的行为或言论?	What cheng-yu is used to condemn behaviors or speeches that are harmful and adverse to social morality?
借花献佛	什么成语常用来比喻借用他人的物品待客或送人?	What cheng-yu is used to refer to using other people's goods to show hospitality or give as gifts?
作壁上观	什么成语原指古时双方激烈交战，自己则在军营四周的围墙上站着看，后多比喻站在一旁看着，不动手帮助?	Which cheng-yu originally described standing by the barracks while watching two sides fighting, and now means standing to the side as a bystander?
泛泛而谈	什么成语多用来指代不深入的一般性的讨论?	What cheng-yu is used to refer to general, shallow discussions?

浅尝辄止	什么成语多用来指一个人对某件事情略微试一下就停下来，不深入钻研?	What cheng-yu is used to describe a person who tries something briefly but stops without delving further into it?
洁身自好	什么成语意为一个人维持他的清廉纯净，而不随波逐流，趋炎附势，有时也意为只顾惜他个人，而不管其他人的事?	What cheng-yu means that a person maintains their integrity and purity instead of following the trend, which can also mean not minding other people's affairs?
洗心革面	什么成语意为一个人清除自己的旧思想，改变旧容貌，常用来比喻彻底悔改?	What cheng-yu means a person changes their old thoughts and appearance, and is often used as a metaphor for complete repentance?
江郎才尽	什么成语原指文人少有文名，晚年诗文无佳句，现在常比喻文思枯竭减退，好的作品逐渐变少?	What cheng-yu describes an author who was once prolific but now cannot produce good work, and means having no more good ideas or work?
泾渭分明	什么成语意为有二条河流,一清一浊,虽合流汇聚，却清浊不混，多用来比喻界限清晰或是非清楚?	What cheng-yu refers to a clear river and a muddy river that converge but don’t mix, which is often used to describe having clear boundaries or being black-and-white?
河东狮吼	什么成语比喻悍妒的妻子对丈夫大吵大闹?	What cheng-yu describes a jealous wife who is screaming at her husband?
流连忘返	什么成语形容沉迷于游乐而没想着回去，后多指留恋某事，舍不得离开，同义词有“乐不思蜀”?	What cheng-yu describes having so much fun that you have no desire to leave, and now refers to being so addicted to something that you don’t want to stop? Its synonym is “le4bu4si1shu3.”
滥竽充数	什么成语比喻无本领的冒充有本领，次货假冒好货?	What cheng-yu describes an incapable person who pretends to be capable, or a bad product that seems like a good product?
浑水摸鱼	什么成语常用来比喻乘混乱的时候从中捞取利益，和趁火打劫是同义词?	What cheng-yu describes taking advantage of chaos, and is a synonym with “cheng4huo3da3jie2”?
投笔从戎	什么成语常用来比喻指文人参加军队?	What cheng-yu describes a literary intellectual joining the army?
指桑骂槐	什么成语意为表面上在指责某人某事，但实际上在拐弯抹角的指责其他的人或事?	What cheng-yu means to accuse someone or something, but to actually refer to another person or thing?
探囊取物	什么成语意为伸手到口袋里拿东西，比喻能够轻而易举地办成某件事情?	What cheng-yu means to reach into your pocket to grab something, which is a metaphor for being able to easily accomplish something?
披荆斩棘	什么成语意为劈开丛生多刺的野生植物，比喻在创业过程中或前进道路上清除障碍，克服重重困难?	What cheng-yu means to split apart thorny wild plants as a metaphor for clearing obstacles and overcoming challenges when starting a business?

招兵买马	什么成语旧时指组织或扩充武装力量，后比喻国家或组织募集并扩充人力?	What cheng-yu was used to refer to the organization or expansion of armed forces, and now refers to the recruitment and expansion of manpower by countries or organizations?
探骊得珠	什么成语原指冒大险得大利，后常比喻文章含义深刻，措辞扼要，得到要领?	What cheng-yu originally meant taking big risks and gaining great profits, but now refers to profound and concisely written articles?
振聋发聩	什么成语意为声音很大，使耳朵不灵的人也听得见，比喻用语言文字唤醒糊涂麻木的人，使他们清醒过来?	What cheng-yu means that a sound is so loud that people with impaired hearing can hear it, and refers to rousing apathetic people?
扬长避短	什么成语意为发挥优点或有利条件，克服缺点或不利条件?	What cheng-yu means exerting advantages and overcoming disadvantages?
抛砖引玉	什么成语常用来比喻用自己不成熟的意见或作品引出别人更好的意见或好作品，常常被用作一种谦虚的表达方式?	What cheng-yu describes using one's immature opinions or works to elicit the better opinions or good works of others, and is used as an expression of modesty?
授人口实	什么成语意为留下给别人非议的把柄?	What cheng-yu describes giving others the opportunity to criticize you?
诲人不倦	什么成语意为教导人特别耐心，从不厌烦?	What cheng-yu means teaching people in a way that is very patient and never bored?
设身处地	什么成语意为假想自己在别人所在的境况，指替别人的情况着想?	What cheng-yu refers to imagining yourself in other people’s situations to be considerate?
语重心长	什么成语指言辞恳切、情意深厚，常常是深沉的劝告或忠告?	What cheng-yu refers to sincere words, deep affection, and often deep advice?
误人子弟	什么成语指因无才或不负责任而对后辈或学生造成了不好的影响?	What cheng-yu refers to creating a bad influence on juniors or students due to a lack of talent or irresponsibility?
诸子百家	什么成语原指先秦时期各种思想的代表人物和各个派别，后用来对先秦至汉初各种流派的总称，有时也会用来指某一学问里不同的流派?	What cheng-yu originally referred to representatives of various thoughts and schools in the pre-Qin period, later referred to various schools of the pre-Qin to the beginning of Han period, and sometimes refers to different schools of thought in certain academic fields?
调虎离山	什么成语比喻用计使对方走开原来的地方，以便乘机行事?	What cheng-yu means to use a trick to make the other person walk away from the original place, in order to take the opportunity to act?
词不达意	什么成语意为话语或文章不能确切地表达出自己的思想和情感?	What cheng-yu means that words or articles cannot accurately express one's thoughts and emotions?
诡计多端	什么成语意为欺诈的手段层出不穷，形容坏主意很多?	What cheng-yu means that fraudulent methods and bad ideas abound?

请君入瓮	什么成语比喻用某人整治别人的办法来整治他自己，意同以其人之道，还治其人之身，以牙还牙?	What cheng-yu means to use a person’s way of treating others towards that person—in other words, to treat a person as they treat others?
话不投机	什么成语意为双方意见或看法等有差异，导致交流不到一起去?	What cheng-yu means that two parties have different viewpoints and opinions, resulting in differences in communication?
红颜薄命	什么成语指女子容貌美丽但遭遇或命运不好?	What cheng-yu refers to a woman who is beautiful but has bad experiences or a bad fate?
纨绔子弟	什么成语原意为形容衣着华美的年轻人，旧时则指官僚、地主等有钱有势人家成天吃喝玩乐、不务正业的后辈，现在也常用来比喻有权有势家庭贪图享受的儿女，意同“花花公子”?	What cheng-yu describes young people who dress beautifully; originally referred to bureaucrats, landlords, and other wealthy people who could have fun all day; now refers to children of rich, powerful families; and is synonymous with “hua1hua1gong1zi0”?
纸上谈兵	什么成语比喻夸夸其谈,不切实际，也比喻只是空谈，不能成为现实，一般认为典故出自战国时期的大将赵括?	What cheng-yu, believed to come from the general Zhao Kuo of the Warring States period, describes being exaggerated or unrealistic?
纲举目张	什么成语意为把大绳子一提起来，一个个网眼就都展开，比喻抓住事物的关键，带动其他环节，也比喻文章条理分明?	What cheng-yu describes how mesh unfolds when big ropes of a net are lifted up, in order to describe catching and organizing a topic’s key points and links well?
纵横天下	什么成语意为在世界上自由来往，没有阻拦，比喻傲视群雄，所向无敌?	What cheng-yu means traveling freely in the world without hindrance, as a metaphor for being arrogant and invincible?
细水长流	什么成语比喻节约使用财物，使其不至于缺乏，也常比喻一点一滴不间断地做某件事?	What cheng-yu describes conserving property such that it does not reach its limits and refers to doing something bit by bit, without any interruptions?
绿林好汉	什么成语指聚集山间反抗封建统治阶级的人们，旧时也指聚众行劫的群盗股匪?	What cheng-yu refers to people who gather in the mountains to resist the feudal ruling class?
统筹兼顾	什么成语意为同时进行几桩事情或占有几样东西，常用来比喻总揽全局，通盘策划?	What cheng-yu means doing several things at the same time and is a metaphor for comprehensively planning for a situation?
纠缠不清	什么成语常形容纷乱，理不出头绪，亦指有意找麻烦，抓住一点不肯放手?	What cheng-yu describes chaos, not having a clue, deliberately looking for trouble, and refusing to let go?
敝帚自珍	什么成语意为将破旧的扫把视作宝物来珍惜，比喻自己的东西虽然并不好或不贵重，但自己很爱惜?	What cheng-yu means to cherish the worn-out broom as a treasure, and describes cherishing your own possessions even if they aren’t good or valuable?

敌众我寡	什么成语指两方对峙，己方的势力与人数和对手相差悬殊?	What cheng-yu describes having two sides meet, with one side having much fewer numbers and less power than their opponent?
散兵游勇	什么成语原指没有统帅而四散而逃的军队，现有指没有组织的集体队伍里独自行动的人?	What cheng-yu originally refers to a fleeing army without a commander, but now refers to a person acting alone in an unorganized team?
数典忘祖	什么成语指谈论历来的制度、事迹时，却连自己先人的职守都不记得了，比喻对于自己的家族或本国历史的无知?	What cheng-yu means discussing past systems and deeds but forgetting your own duties, a metaphor for ignorance of the history of your own family or country?
敏而好学	什么成语意为天资聪颖而又热爱追求知识，常与“不耻下问”出现在一起?	What cheng-yu means being talented and intellectual, and often occurs with the phrase “bu4chi3xia4men4”?
故伎重演	什么成语意为再一次使用以前使用过的老花招或老手法?	What cheng-yu means repeating the same old trick?
政通人和	什么成语出自范仲淹的《岳阳楼记》，后常用来形容国泰民安?	What cheng-yu comes from Fan Zhongyan's "The Story of Yueyang Tower", which is often used to describe peacetime?
敬而远之	什么成语意为对于某人某事，表面上表示尊重，实际上不愿接近，常含有贬义?	What cheng-yu means being respectful on the surface to someone or something but not wanting to further engage, and often carries a derogatory meaning?
敷衍了事	什么成语意为办事马马虎虎，只求应付过去就算结束?	What cheng-yu means doing things carelessly just to get them done?
阳奉阴违	什么成语指玩弄两面派手法，表面上遵从，暗地里却反对甚至不遵守?	What cheng-yu means playing tricks on two parties or being respectful only on the surface?
阳春白雪	什么成语常用来比喻高深的不通俗的文学艺术?	What cheng-yu describes works of art and literature that are profound and elite?
阴阳怪气	什么成语形容言谈、举止等诡异，不寻常，或说话、态度不真诚,让人估摸不透，有时也意为冷言冷语?	What cheng-yu describes weird, unpredictable, insincere behavior or talk, and can sometimes also describe sarcastic, mean talk?
邯郸学步	什么成语比喻一味模仿别人，非但没有模仿到别人的长处，反倒失去了自身的特色，近义词有“东施效颦”?	What cheng-yu means to imitate someone but not their strengths, and to lose one’s own features in the process? Its synonym is “dong1shi1xiao4pin2.”
隔墙有耳	什么成语比喻即使秘密商量，别人也可能知道，也用于劝人说话小心，免得泄露?	What cheng-yu means discussing things in secret but other people still knowing, and is used to encourage people to talk carefully?
阴魂不散	什么成语常用来比喻坏人、坏事虽已清除，但其所造成的恶劣影响还在起作用?	What cheng-yu means that although bad people and bad things have been eliminated, their harmful effects still continue?

随心所欲	什么成语意为完全按照自己的意愿去行事，想干什么就干什么?	What cheng-yu means just doing what you want to do?
剑拔弩张	什么成语原形容书法笔力深厚，后多形容气势逼人，或形势紧张，双方表现出敌意或作出敌对的行动，战斗一触即发?	What cheng-yu originally described the profound strength of the calligraphy pen, but later was used to describe a forceful or tense situation, where the two sides showed hostility before the beginning of battle?
别有用心	什么成语指在言论或行为中暗含其他不可告人的企图?	What cheng-yu means to imply ulterior motives in speech or behavior?
削足适履	什么成语意为因为鞋小脚大，就把脚减去一块来凑和鞋的大小，比喻不合理的牵就凑合或不顾具体条件，生搬硬套?	What cheng-yu describes forcing your foot into a shoe that's too small, and is a metaphor for forcing yourself to fit what other people want?
刎颈之交	什么成语意为两人的友谊深厚到可以用刀割脖子，常用来比喻可以同生死、共患难的朋友?	What cheng-yu literally means that the friendship between two people is so deep that you could cut their necks with a knife, and is often used as a metaphor for friends who can live, die, and share adversity together?
刮目相看	什么成语意为用新的眼光审视别人，比喻去掉旧日的意见，用新的眼光来对待人或事物?	What cheng-yu means looking at others with new eyes, and is a metaphor to get rid of old opinions and treat people with a new perspective?
刚柔并济	什么成语意同软硬兼施，强硬和温和的手段一起使用?	What cheng-yu means treating others with carrots and sticks?
割据一方	什么成语意为凭借武力占据部分领土，与中央政权对立?	What cheng-yu means occupying part of a territory by force and opposing its central government?
彼竭我盈	什么成语意为敌方的士气低迷，而我方的士气正旺，出自《左传》节选《曹刿论战》?	What cheng-yu means that the enemy's morale is low and our morale is high, and comes from the "Cao Ku Debate" excerpt from "Zuo Kuan"?
徒劳无功	什么成语意为即使付出了努力也不会有任何的成效可言?	What cheng-yu means that even if you put in effort, there will be no results at all?
待价而沽	什么成语意为等到好的金额再出售，比喻做事等待某种条件，或怀才等待赏识者重用?	What cheng-yu literally means to wait to sell until the price is good and is a metaphor for waiting to do something until the conditions are right or until someone appreciates it?
徒有虚名	什么成语形容人或事的声誉与实际的情况不相符?	What cheng-yu means that a person's reputation or situation does not match reality?
循循善诱	什么成语意为善于有步骤地辅助引导别人学习?	What cheng-yu means being good at assisting others with learning step by step?
微不足道	什么成语指意义、价值等小得没有提的必要?	What cheng-yu means that a certain meaning, value, etc. is not necessary to mention?

徇私枉法	什么成语意为为了私人利益而用欺骗的方法做违法乱纪的事?	What cheng-yu means to use deceitful methods to violate the law for personal gain?
如鲠在喉	什么成语比喻心里有话没有说出来，非常难受，仿佛被鱼骨头卡住了一样?	What cheng-yu describes feeling pain from not verbalizing something important, as if there were a fish bone stuck inside of you?
如丧考妣	什么成语形容人好像失去了自己的父母一样伤心?	What cheng-yu describes people being as sad as though they have lost their parents?
如日中天	什么成语意为像正午的太阳一样，比喻事物正发展到十分兴盛的阶段?	What cheng-yu describes a sun at noon and is a metaphor for a period of flourishing?
始乱终弃	什么成语指开始加以玩弄，最后却不管不顾了，多指男子玩弄女性的邪恶行为?	What cheng-yu describes playing with something but losing interest, and is a metaphor for men’s malicious behavior towards women?
始作俑者	什么成语常用来比喻首先做某件坏事的人，和罪魁祸首是同义词?	What cheng-yu refers to the first person who did something bad in a situation and is a synonym for “zui4kui2huo4shou3”?
嬉笑怒骂	什么成语指人的各种情感与动作，常用来比喻不论什么题材和形式，都能不拘一格任意发挥，写出好文章来?	What cheng-yu describes people’s various feelings or actions, and is used as a metaphor that no matter the subject matter or style, one can still express themselves and write well?
姗姗来迟	什么成语旧时形容女子走路缓慢从容的样子，现多形容慢腾腾地而晚到?	What cheng-yu originally described a woman walking along in a slow and carefree manner, and now describes walking slowly and arriving late?
妙手偶得	什么成语指用来形容文学素养很深的人，出于灵感，即可意想不到间得到妙语佳作，出自陆游的诗句?	What cheng-yu, which originated from Lu You’s poems, is used to describe how a person with great literary accomplishment can unexpectedly create a witty masterpiece by drawing on inspiration?
姹紫嫣红	什么成语常形容花的品种繁多,五颜六色,娇艳美丽?	What cheng-yu often describes the color and beauty of flowers?
肝脑涂地	什么成语原指人惨死的样子，后用来形容竭尽忠诚，任何牺牲都在所不惜?	What cheng-yu originally described a person dying tragically and now describes being so loyal that you would sacrifice everything?
朝令夕改	什么成语意为早上的决定，到晚上就变了，常用来比喻经常改变主张和办法，一会儿一个样?	What cheng-yu means to make a decision in the morning but change it in the evening, and is a metaphor for changing opinions and methods frequently?
脍炙人口	什么成语原意为切细的烤肉大家都爱吃，后比喻好的诗文广泛流传受群众赞美?	What cheng-yu originally described cutting meat into fine pieces to share with everyone, and now describes the masses sharing good poetry?
枕戈待旦	什么成语意思是立志杀敌，把头躺在着武器上	What cheng-yu means to sleep with your head

	睡觉等着天亮，形容时刻准备作战?	on a weapon, waiting for dawn to kill your enemy? It is a metaphor for being ready to fight.
格物致知	什么成语，原为儒家的一个重要思想，现常指不断的穷究事物的原理，从而获得知识?	What cheng-yu was originally an important thought of Confucianism, but now refers to studying the principle of something to gain knowledge?
权宜之计	什么成语指为了应付某种情况而暂时采取的办法?	What cheng-yu refers to a temporary way to deal with a certain situation?
相濡以沫	什么成语意为泉水干了，鱼吐沫互相润湿，比喻一同在困难的处境里，用微薄的力量彼此帮助?	What cheng-yu describes fish spitting on each other to stay moist in a dry area, which is a metaphor for helping each other with meager strength in a difficult situation?
睹物思人	什么成语意为看到死者或离去的留下的东西，就引起了对他的思念?	What cheng-yu describes thinking of someone who’s passed away after seeing their possessions?
瞠目结舌	什么成语意为瞪着眼睛说不出话来，形容窘困或惊呆的样子?	What cheng-yu means being speechless with staring eyes, to describe a look of embarrassment or shock?
瞻前顾后	什么成语意为看看前面，再看看后面，指办事考虑细致周密,也指顾虑太多,犹豫不定?	What cheng-yu means to look to the front and then look to the back, describing careful consideration or hesitation?
冯唐易老	什么成语常被用来感慨“生不逢时或表示因年迈而不能再有一番作为，曾出现在王勃的《滕王阁序》中?	What cheng-yu is often used to express feelings about untimely birth or to express that one cannot do anything because of old age, and originally appeared in Wang Bo's Preface to the Pavilion of the Teng King?

Appendix B

Experiment 1: Cheng-yu Targets, Primes, and Filler Words

Cheng-yu Target	Cheng-yu First Character Pinyin	Atonal Syllable Frequency	Tonal Syllable Frequency	Atonal Syllable Frequency Category	Tonal Syllable Frequency Category	First Phoneme Prime	First Phoneme Prime Pinyin	First Syllable Prime	First Syllable Prime Pinyin	Un-Related Control	Filler Word 1	Filler Word 2	Filler Word 3	Filler Word 4
仗义疏财	zhang4	341340	N/A	Lower	Higher	制定	zhi4 ding4	帐子	zhang4 zi0	联盟	表面	曾经	儿童	接着
假公济私	jia3	1051033	32247	Higher	Lower	举起	ju3qi3	甲方	jia3 fang1	屋顶	日本	地位	思想	意愿
停滞不前	ting2	314552	111540	Lower	Lower	糖果	tang2 guo3	庭院	ting2 yuan4	了解	加法	需要	父母	整体
借题发挥	jie4	1109315	450949	Higher	Higher	眷顾	juan4 gu4	界线	jie4xian4	动作	永远	不满	色彩	抗议
俨乎其然	yan3	791181	223257	Higher	Higher	饮茶	yin3cha 2	演变	yan3 bian4	进步	大陆	中文	根本	除了
俯首帖耳	fu2	1056555	290495	Higher	Higher	房间	fang2 jian3	服役	fu2yi4	结果	程式	实在	成就	美元
倒行逆施	dao4	1788900	1583563	Higher	Higher	地点	di4dian3	道路	dao4lu4	遊戏	妻子	主张	天下	报导
偃旗息鼓	yan3	791181	223257	Higher	Higher	野外	ye3wai4	眼睛	yan3 jing1	比例	师生	结合	经由	工厂
伤风败俗	shang1	1292610	165038	Higher	Higher	身体	shen1ti3	商家	shang1 jia1	运用	结构	快乐	一旦	正式
借花献佛	jie4	1109315	450949	Higher	Higher	距离	ju4li2	介意	jie4yi4	互动	你们	档案	小孩	弄乱
作壁上观	zuo4	893830	827478	Higher	Higher	自己	zi4ji3	坐车	zuo4 che1	声音	兄弟	而已	对方	通讯
泛泛而谈	fan4	459450	158327	Lower	Higher	付钱	fu4qian2	犯罪	fan4zui4	减少	总是	合理	行为	保持
浅尝辄止	qian3	638821	23042	Lower	Lower	启动	qi3dong 4	谴责	qian3 ze2	竞争	保育	透过	设备	增加
洁身自好	jie2	1109315	339958	Higher	Higher	决定	jue2 ding3	节电	jie2dian4	少数	恢复	生命	电脑	支持
洗心革面	xi3	1082565	86117	Higher	Lower	雪白	xue3 bai2	喜欢	xi3 huan1	追求	条件	教室	工具	整理
江郎才尽	jiang1	511050	85310	Lower	Lower	居住	jv1zhu4	将来	jiang1 lai2	主人	西瓜	摄影	资料	构成
泾渭分明	jing4	1186243	779888	Higher	Higher	具体	ju4ti3	竞赛	jing4sai4	情绪	组织	老家	的确	毕业
河东狮吼	he2	1635213	358767	Higher	Higher	孩子	hai2zi3	和善	he2 shan4	小组	政大	金融	看见	就是
流连忘返	liu2	351731	245324	Lower	Higher	来往	lai2 wang3	留下	liu2xia4	经营	召开	管制	美国	降低
滥竽充数	lan4	142369	14599	Lower	Lower	累死	lei4si3	烂掉	lan4 diao4	记得	院长	大概	健康	相对
浑水摸鱼	hun2	96486	24671	Lower	Lower	含泪	han2lei4	馄饨	hun2 tun2	住宅	年轻	要求	学术	出去
投笔从戎	tou2	400461	354619	Lower	Higher	徒弟	tu2di4	头发	tou2fa0	海外	劳工	关于	一样	主义
指桑骂槐	zhi3	3185308	655690	Higher	Higher	长辈	zhang3	只要	zhi3yao4	法国	角色	衣服	称为	地球

							bei4							
探囊取物	tan4	224714	61933	Lower	Lower	透明	tou4 ming2	叹气	tan4qi4	最佳	不断	以下	施工	成果
披荆斩棘	pi1	376008	78465	Lower	Lower	喷水	pen1shui3	劈柴	pi1chai2	回到	意思	展开	改善	应用
招兵买马	zhao1	289937	41455	Lower	Lower	知道	zhi1dao3	着急	zhao1ji2	老板	西方	处理	文学	名字
探骊得珠	tan4	224714	61933	Lower	Lower	替换	ti4huan4	叹息	tan4xi1	办理	承认	谢谢	遛狗	还是
振聋发聩	zhen4	418098	133951	Lower	Lower	炸弹	zha4dan4	镇痛	zhen4tong4	不良	害怕	吓人	好像	欢迎
扬长避短	yang2	698164	178735	Higher	Higher	牙齿	ya2chi3	羊群	yang2qun2	想法	举行	儿子	免费	国外
抛砖引玉	pao1	99236	10477	Lower	Lower	批评	pi1ping2	庖丁	pao1ding1	引起	可以	适合	很多	病人
授人口实	shou4	803601	272962	Higher	Higher	晒太阳	shai4tai4yang2	受够	shou4gou4	关心	扩大	存在	开发	日子
诲人不倦	hui3	1181130	32258	Higher	Lower	罕见	han3jian4	毁了	hui3le0	投入	苹果	有点	女性	实现
设身处地	she4	433892	413008	Lower	Higher	上当	shang4dang4	射穿	she4chuan1	山羊	纽约	专利	坏人	安全
语重心长	yu3	1713834	73311	Higher	Lower	哑巴	ya3ba1	于此	yu3ci3	学生	作法	竟然	沟通	想要
误人子弟	wu4	1372087	593990	Higher	Higher	忘掉	wang4diao4	物理	wu4li3	教学	安排	费用	幸福	可能
诸子百家	zhu1	958453	91765	Higher	Lower	沾水	zhan1shui3	朱砂	zhu1sha1	大部分	时代	医学	面包	梦想
调虎离山	diao4	167083	158370	Lower	Higher	大人	da4ren2	吊销	diao4xiao1	接触	具备	某些	真的	现场
词不达意	ci2	657819	90106	Higher	Lower	惭愧	can2kui4	瓷碗	ci2wan3	适当	博物馆	获得	集中	辛苦
诡计多端	gui3	280303	40512	Lower	Lower	古代	gu3dai4	鬼脸	gui3lian3	超过	书包	就是说	输入	来自
请君入瓮	qing3	774492	102979	Higher	Lower	起来	qi3lai2	顷刻	qing3ke4	解决	现实	食物	业务	上面
话不投机	hua4	807991	684865	Higher	Higher	恨意	hen4yi4	化学	hua4xue2	加入	外国	完整	感到	旅遊
红颜薄命	hong2	149967	125266	Lower	Lower	蛤蟆	ha2ma1	洪水	hong2shui3	上课	饼干	积极	处於	一起
纨绔子弟	wan2	452252	180878	Lower	Higher	无法	wu2fa3	完蛋	wan2dan4	合作	学校	充分	蝴蝶	胳膊
纸上谈兵	zhi3	3185308	655690	Higher	Higher	眨眼	zha3yan3	只有	zhi3you3	小时	文艺	表明	罗马	黄瓜
纲举目张	gang1	140899	82689	Lower	Lower	哥特	ge1te4	缸砖	gang1zhuan1	资金	鼻子	走路	手套	舞会
纵横天下	zong4	271651	20599	Lower	Lower	作业	zuo4ye4	粽子	zong4zi0	政策	北京	啤酒	电视	离开
细水长流	xi4	1082565	292216	Higher	Higher	限制	xian4zhi4	戏语	xi4yu3	蓝色	可乐	世界	气球	利用
绿林好汉	lv4	276875	N/A	Lower	Higher	恋爱	lian4ai4	律师	lv4shi1	围巾	键盘	地毯	汽车	成长
统筹兼顾	tong3	909188	177494	Higher	Higher	毯子	tan3zi1	桶子	tong3zi0	亚洲	火腿	玩具	表姐	面对

纠缠不清	jiu1	1166024	111268	Higher	Lower	军人	jun1ren2	究竟	jiu1jing4	大象	饮料	行李	表示	担心
敝帚自珍	bi4	421278	331746	Lower	Higher	不法	bu4fa3	必须	bi4xu1	眉毛	地铁	工作	事务	个性
敌众我寡	di2	1724350	105286	Higher	Lower	答礼	da2li3	迪厅	di2ting1	经常	奶酪	组成	桌子	不少
散兵游勇	san3	349119	5511	Lower	Lower	锁定	suo3ding4	伞柄	san3bing4	小熊	给予	官员	或者	主管
数典忘祖	shu4	867809	471728	Higher	Higher	善良	shan4liang2	树枝	shu4zhi1	印度	白菜	选择	举办	到底
敏而好学	min3	354208	18412	Lower	Lower	买东西	mai3dong1xi1	闽菜	min3cai4	网络	线上	辅导	这些	深刻
故伎重演	gu4	432908	177184	Lower	Higher	盖上	gai4shang4	痼疾	gu4ji2	比较	自动	明显	重大	努力
政通人和	zheng4	983292	742315	Higher	Higher	炸毁	zha4hui3	郑州	zheng4zhou1	袜子	洋葱	关键	譬如	见到
敬而远之	jing4	1186243	779888	Higher	Higher	嫁妆	jia4zhuang1	镜子	jing4zi0	瑞典	香肠	能够	无论	仔细
敷衍了事	fu1	1056555	13145	Higher	Lower	疯子	feng1zi3	父亲	fu1qin0	葡萄	准备	相信	帮助	工会
阳奉阴违	yang2	698164	178735	Higher	Higher	椰子	ye2zi0	羊毛	yang2mao2	死亡	文字	制度	污染	相当
阳春白雪	yang2	698164	178735	Higher	Higher	于是	yu2shi4	扬手	yang2shou3	从事	厨房	问题	显得	发生
阴阳怪气	yin1	750738	489220	Higher	Higher	鸭蛋	ya1dan4	音乐	yin1yue4	找到	开门	男生	特征	公里
邯郸学步	han2	203571	86743	Lower	Lower	湖广	hu2guang3	寒假	han2jia4	适应	因此	市民	提高	作者
隔墙有耳	ge2	1748292	250512	Higher	Higher	国家	guo2jia1	革命	ge2ming4	艺术	反映	提升	去掉	以前
阴魂不散	yin1	750738	489220	Higher	Higher	约上	yue1shang4	因由	yin1you2	逐渐	特殊	基本	忽然	加强
随心所欲	sui2	243720	87519	Lower	Lower	苏州	su1zhou1	隋朝	sui2chao2	公斤	听说	校长	节目	来到
剑拔弩张	jian4	1451889	1167654	Higher	Higher	巨大	jv4da4	建议	jian4yi4	考试	活动	青年	这样	为什么
别有用心	bie2	188222	N/A	Lower	Higher	拔草	ba2cao3	蹩脚	bie2jiao3	现象	人员	破坏	之前	进口
削足适履	xue1	572292	9318	Lower	Lower	虚弱	xu1ruo4	薛卞	xue1bian4	蛋糕	所以	钢琴	花瓶	打架
刎颈之交	wen3	695970	37065	Higher	Lower	往前	wang3qian2	稳定	wen3ding4	先生	不得	团体	母亲	重视
刮目相看	gua1	43244	13305	Lower	Lower	该打	gai1da3	瓜果	gua1guo3	甚至	部分	上海	介绍	危机
刚柔并济	gang1	140899	82689	Lower	Lower	孤独	gu1du2	肛门	gang1men2	细胞	难以	这么	连线	研究
割据一方	ge1	1748292	96813	Higher	Lower	姑妈	gu1ma1	哥哥	ge1ge1	自然	有没有	体育	兴建	房子
彼竭我盈	bi3	421278	59136	Lower	Lower	本来	ben3lai2	比赛	bi3sai4	如果	关怀	维护	肯定	否则
徒劳无功	tu2	341681	155921	Lower	Lower	台北	tai2bei3	图片	tu2pian4	主持	意见	不会	完成	空间
待价而沽	dai4	497044	477150	Lower	Higher	地道	di4dao4	代表	dai4biao3	资讯	坏蛋	同仁	办公室	理念
徒有虚名	tu2	341681	155921	Lower	Lower	台阶	tai2jie1	涂漆	tu2qi1	人性	障碍	一点	独立	冲突

循循善诱	xun2	169768	74826	Lower	Lower	习惯	xi2guan4	询问	xun2wen4	其实	因素	文章	电影	发行
微不足道	wei1	2092014	170112	Higher	Higher	歪掉	wai1diao4	威胁	wei1xie2	研讨会	期间	之下	人士	表现
徇私枉法	xun2	169768	74826	Lower	Lower	闲着	xian2zhe0	寻找	xun2zhao3	有趣	培养	博士	课程	研发
如鲠在喉	ru2	669787	456040	Higher	Higher	人们	ren2men	孺子	ru2zi3	流行	投资	心灵	或是	似乎
如丧考妣	ru2	669787	456040	Higher	Higher	人类	ren2lei4	蠕动	ru2dong4	直接	成为	商品	那么	衬衫
如日中天	ru2	669787	456040	Higher	Higher	仍然	reng2ran2	儒家	ru2jia1	生存	观察	进行	通常	享受
始乱终弃	shi3	7050291	536989	Higher	Higher	水滴	shui3di1	史诗	shi3shi1	注意	推出	维持	焦点	规模
始作俑者	shi3	7050291	536989	Higher	Higher	数数	shu3shu4	使用	shi3yong4	专案	不可	运作	河川	心情
嬉笑怒骂	xi1	1082565	583964	Higher	Higher	先进	xian1jin4	希望	xi1wang4	总统	图书馆	动物	居住	通信
姗姗来迟	shan1	284678	186391	Lower	Higher	石头	shi1tou2	山峰	shan1feng1	充满	愈来愈	配合	校方	终于
妙手偶得	miao4	68770	28385	Lower	Lower	末日	mo4ri4	庙宇	miao4yu2	中国人	不易	开车	基础	德国
姹紫嫣红	cha4	255265	59990	Lower	Lower	斥责	chi4ze2	岔子	cha4zi0	主席	一半	国小	时间	新加坡
肝脑涂地	gan1	426276	37093	Lower	Lower	鸽子	ge1zi0	甘甜	gan1tian2	以后	这样子	销售	建立	情形
朝令夕改	zhao1	289937	41455	Lower	Lower	中介	zhong1jie4	招聘	zhao1pin4	设施	公司	认为	成功	立委
脍炙人口	kuai4	163050	163050	Lower	Higher	看望	kan4wang4	快车	kuai4che1	整合	教育局	干部	市场	扮演
枕戈待旦	zhen3	418098	20595	Lower	Lower	肿瘤	zhong3liu2	诊断	zhen3duan4	消费者	因应	并且	吃饭	看到
格物致知	ge2	1748292	250512	Higher	Higher	骨头	gu3tou	革新	ge2xin2	英文	统一	事实	这里	考虑
权宜之计	quan2	503025	470281	Lower	Higher	骑马	qi2ma3	全部	quan2bu4	公尺	统计	主要	以免	拒绝
相濡以沫	xiang1	1575940	110391	Higher	Lower	稀奇	xi1 qi2	香气	xiang1qi4	结婚	水准	不管	馒头	生活
睹物思人	du3	248897	16538	Lower	Lower	逮捕	dai3bu3	笃定	du3ding4	选举	位于	过程	提昇	员工
瞠目结舌	cheng1	857501	5628	Higher	Lower	吃惊	chi1jing1	称颂	cheng1song4	使得	大学	感情	主任	可爱
瞻前顾后	zhan1	584585	10883	Lower	Lower	中间	zhong1jian1	沾上	zhan1shang4	吸引	思考	策略	教师	缺乏
冯唐易老	feng2	289836	15760	Lower	Lower	福气	fu2qi4	缝纫	feng2ren4	出现	观点	所有	眼前	同意

Appendix C

Experiment 2: Cheng-yu Targets, Primes, and Filler Words

Cheng-yu Target	First Radical	First Radical Frequency Category	First Radical Prime	Unrelated Control	Filler Word 1	Filler Word 2	Filler Word 3	Filler Word 4
仗义疏财	亻	Higher	仇恨	联盟	表面	曾经	儿童	接着
假公济私	亻	Higher	仁慈	屋顶	日本	地位	思想	意愿
停滞不前	亻	Higher	仙人	了解	加法	需要	父母	整体
借题发挥	亻	Higher	仪器	动作	永远	不满	色彩	抗议
俨乎其然	亻	Higher	仆从	进步	大陆	中文	根本	除了
俯首帖耳	亻	Higher	休息	结果	程式	实在	成就	美元
倒行逆施	亻	Higher	仿佛	遊戏	妻子	主张	天下	报导
偃旗息鼓	亻	Higher	伟大	比例	师生	结合	经由	工厂
伤风败俗	亻	Higher	价值	运用	结构	快乐	一旦	正式
借花献佛	亻	Higher	例子	互动	你们	档案	小孩	弄乱
作壁上观	亻	Higher	仍然	声音	兄弟	而已	对方	通讯
泛泛而谈	氵	Higher	游泳	减少	总是	合理	行为	保持
浅尝辄止	氵	Higher	汉语	竞争	保育	透过	设备	增加
洁身自好	氵	Higher	浮动	少数	恢复	生命	电脑	支持
洗心革面	氵	Higher	汗渍	追求	条件	教室	工具	整理
江郎才尽	氵	Higher	没落	主人	西瓜	摄影	资料	构成
泾渭分明	氵	Higher	派对	情绪	组织	老家	的确	毕业
河东狮吼	氵	Higher	法律	小组	政大	金融	看见	就是
流连忘返	氵	Higher	注册	经营	召开	管制	美国	降低
滥竽充数	氵	Higher	沉默	记得	院长	大概	健康	相对
浑水摸鱼	氵	Higher	沙漠	住宅	年轻	要求	学术	出去
投笔从戎	扌	Higher	抄袭	海外	劳工	关于	一样	主义
指桑骂槐	扌	Higher	拘束	法国	角色	衣服	称为	地球
探囊取物	扌	Higher	扩散	最佳	不断	以下	施工	成果
披荆斩棘	扌	Higher	搜索	回到	意思	展开	改善	应用
招兵买马	扌	Higher	执行	老板	西方	处理	文学	名字
探骊得珠	扌	Higher	批发	办理	承认	谢谢	遛狗	还是
振聋发聩	扌	Higher	抽出	不良	害怕	吓人	好像	欢迎
扬长避短	扌	Higher	打击	想法	举行	儿子	免费	国外
抛砖引玉	扌	Higher	技术	引起	可以	适合	很多	病人
授人口实	扌	Higher	拥有	关心	扩大	存在	开发	日子
诲人不倦	讠	Higher	训练	投入	苹果	有点	女性	实现
设身处地	讠	Higher	访问	山羊	纽约	专利	坏人	安全
语重心长	讠	Higher	谣言	学生	作法	竟然	沟通	想要
误人子弟	讠	Higher	说辞	教学	安排	费用	幸福	可能

诸子百家	ㄧ	Higher	认识	大部分	时代	医学	面包	梦想
调虎离山	ㄧ	Higher	记录	接触	具备	某些	真的	现场
词不达意	ㄧ	Higher	调整	适当	博物馆	获得	集中	辛苦
诡计多端	ㄧ	Higher	议论	超过	书包	就是说	输入	来自
请君入瓮	ㄧ	Higher	证据	解决	现实	食物	业务	上面
话不投机	ㄧ	Higher	误导	加入	外国	完整	感到	旅遊
红颜薄命	ㄠ	Higher	纠结	上课	饼干	积极	处於	一起
纨绔子弟	ㄠ	Higher	结束	合作	学校	充分	蝴蝶	胳膊
纸上谈兵	ㄠ	Higher	纯粹	小时	文艺	表明	罗马	黄瓜
纲举目张	ㄠ	Higher	纽带	资金	鼻子	走路	手套	舞会
纵横天下	ㄠ	Higher	绝对	政策	北京	啤酒	电视	离开
细水长流	ㄠ	Higher	纹路	蓝色	可乐	世界	气球	利用
绿林好汉	ㄠ	Higher	经历	围巾	键盘	地毯	汽车	成长
统筹兼顾	ㄠ	Higher	纲领	亚洲	火腿	玩具	表姐	面对
纠缠不清	ㄠ	Higher	纸片	大象	饮料	行李	表示	担心
敝帚自珍	ㄡ	Lower	收回	眉毛	地铁	工作	事务	个性
敌众我寡	ㄡ	Lower	救援	经常	奶酪	组成	桌子	不少
散兵游勇	ㄡ	Lower	故事	小熊	给予	官员	或者	主管
数典忘祖	ㄡ	Lower	改变	印度	白菜	选择	举办	到底
敏而好学	ㄡ	Lower	放弃	网络	线上	辅导	这些	深刻
故伎重演	ㄡ	Lower	教育	比较	自动	明显	重大	努力
政通人和	ㄡ	Lower	散文	袜子	洋葱	关键	譬如	见到
敬而远之	ㄡ	Lower	敦促	瑞典	香肠	能够	无论	仔细
敷衍了事	ㄡ	Lower	数字	葡萄	准备	相信	帮助	工会
阳奉阴违	ㄗ	Lower	队伍	死亡	文字	制度	污染	相当
阳春白雪	ㄗ	Lower	陕西	从事	厨房	问题	显得	发生
阴阳怪气	ㄗ	Lower	陆地	找到	开门	男生	特征	公里
邯郸学步	ㄗ	Lower	降落	适应	因此	市民	提高	作者
隔墙有耳	ㄗ	Lower	防守	艺术	反映	提升	去掉	以前
阴魂不散	ㄗ	Lower	隆重	逐渐	特殊	基本	忽然	加强
随心所欲	ㄗ	Lower	陷入	公斤	听说	校长	节目	来到
剑拔弩张	ㄐ	Lower	列车	考试	活动	青年	这样	为什么
别有用心	ㄐ	Lower	判断	现象	人员	破坏	之前	进口
削足适履	ㄐ	Lower	刚猛	蛋糕	所以	钢琴	花瓶	打架
刎颈之交	ㄐ	Lower	利益	先生	不得	团体	母亲	重视
刮目相看	ㄐ	Lower	剧情	甚至	部分	上海	介绍	危机
刚柔并济	ㄐ	Lower	制作	细胞	难以	这么	连线	研究
割据一方	ㄐ	Lower	创造	自然	有没有	体育	兴建	房子
彼竭我盈	ㄔ	Lower	彻底	如果	关怀	维护	肯定	否则
徒劳无功	ㄔ	Lower	徘徊	主持	意见	不会	完成	空间

待价而沽	彳	Lower	律令	资讯	坏蛋	同仁	办公室	理念
徒有虚名	彳	Lower	征询	人性	障碍	一点	独立	冲突
循循善诱	彳	Lower	德行	其实	因素	文章	电影	发行
微不足道	彳	Lower	往返	研讨会	期间	之下	人士	表现
徇私枉法	彳	Lower	很好	有趣	培养	博士	课程	研发
如鲠在喉	女	Lower	好奇	流行	投资	心灵	或是	似乎
如丧考妣	女	Lower	姐妹	直接	成为	商品	那么	衬衫
如日中天	女	Lower	娉婷	生存	观察	进行	通常	享受
始乱终弃	女	Lower	姓名	注意	推出	维持	焦点	规模
始作俑者	女	Lower	妇女	专案	不可	运作	河川	心情
嬉笑怒骂	女	Lower	媒介	总统	图书馆	动物	居住	通信
姗姗来迟	女	Lower	奶牛	充满	愈来愈	配合	校方	终于
妙手偶得	女	Lower	婚姻	中国人	不易	开车	基础	德国
姹紫嫣红	女	Lower	好处	主席	一半	国小	时间	新加坡
肝脑涂地	月	Lower	服务	以后	这样子	销售	建立	情形
朝令夕改	月	Lower	肥胖	设施	公司	认为	成功	立委
脍炙人口	月	Lower	脖子	整合	教育局	干部	市场	扮演
枕戈待旦	木	Lower	棋子	消费者	因应	并且	吃饭	看到
格物致知	木	Lower	机器	英文	统一	事实	这里	考虑
权宜之计	木	Lower	社会	公尺	统计	主要	以免	拒绝
相濡以沫	目	Lower	盼望	结婚	水准	不管	馒头	生活
睹物思人	目	Lower	眯眼	选举	位于	过程	提昇	员工
瞠目结舌	目	Lower	眼睛	使得	大学	感情	主任	可爱
瞻前顾后	目	Lower	瞬间	吸引	思考	策略	教师	缺乏
冯唐易老	冫	Lower	冰块	出现	观点	所有	眼前	同意

Appendix D

Recognition Test Multiple Choice Answers

Choice A	Choice B	Choice C	Choice D	Correct Answer
仗义疏财	仗义执言	散尽千金	日月同辉	A
假仁假义	假公济私	公私不分	长驱直入	B
停杯投箸	故国神游	停滞不前	踟蹰不前	C
借尸还魂	小题大做	铲奸除恶	借题发挥	D
俨乎其然	眼高手低	一本正经	自怨自艾	A
俯仰之间	俯首帖耳	低声下气	水滴石穿	B
道听途说	千里之行	倒行逆施	民不聊生	C
匿迹潜形	偃文修武	目不斜视	偃旗息鼓	D
伤风败俗	速战速决	伤春悲秋	伤天害理	A
借刀杀人	借花献佛	顺水人情	高风亮节	B
隔岸观火	十全十美	作壁上观	左右为难	C
空洞无物	泛泛之辈	以下犯上	泛泛而谈	D
浅尝辄止	深入浅出	半途而废	无怨无悔	A
继往开来	洁身自好	结草衔环	孤芳自赏	B
洗耳恭听	金盆洗手	洗心革面	求之不得	C
黔驴技穷	不郎不秀	心旷神怡	江郎才尽	D
泾渭分明	南橘北枳	二龙戏珠	模棱两可	A
夫妻反目	河东狮吼	恒河沙数	上下求索	B
流落他乡	国而忘家	流连忘返	群策群力	C
碌碌无为	忧国忧民	鱼龙混杂	滥竽充数	D
浑水摸鱼	不劳而获	缘木求鱼	浪子回头	A
投桃报李	投笔从戎	弃医从文	广袤无垠	B
旁敲侧击	指鹿为马	指桑骂槐	稍纵即逝	C
求贤若渴	得心应手	叹为观止	探囊取物	D
披荆斩棘	关山难越	披星戴月	冲锋陷阵	A
结党营私	招兵买马	招风惹雨	抽刀断水	B
耐人寻味	牝牡骊黄	探骊得珠	望洋兴叹	C
醍醐灌顶	震耳欲聋	举步维艰	振聋发聩	D
扬长避短	避重就轻	为所欲为	欲扬先抑	A
一己之见	抛砖引玉	抛头露面	以卵击石	B
寻花问柳	授业解惑	授人口实	似是而非	C
毁于一旦	孜孜不倦	修生养性	诲人不倦	D
设身处地	处心积虑	含沙射影	身临其境	A

千言万语	语重心长	吐肝露胆	天高气爽	B
金玉其外	误入歧途	误人子弟	言谈举止	C
百花齐放	颐指气使	反求诸己	诸子百家	D
调虎离山	声东击西	调兵遣将	命途多舛	A
拐弯抹角	词不达意	强词夺理	乘风破浪	B
足智多谋	装神弄鬼	诡计多端	将计就计	C
瓮中捉鳖	以毒攻毒	云淡风轻	请君入瓮	D
话不投机	话中有话	貌合神离	喜出望外	A
红颜祸水	红颜薄命	命在旦夕	晴天霹雳	B
挥金如土	万事大吉	纨绔子弟	腥风血雨	C
空谈误国	洛阳纸贵	自惭形秽	纸上谈兵	D
纲举目张	刚直不阿	提纲挈领	举世闻名	A
纵横捭阖	纵横天下	纵虎归山	千篇一律	B
开源节流	细致入微	细水长流	顺风顺水	C
曲终人散	绿草如茵	山野村夫	绿林好汉	D
统筹兼顾	运筹帷幄	如痴如醉	一统天下	A
不离不弃	纠缠不清	闪烁其词	腰缠万贯	B
自视甚高	高深莫测	敝帚自珍	敝衣枵腹	C
高下立判	敌国外患	稀疏平常	敌众我寡	D
散兵游勇	游必有方	残兵败将	无法无天	A
崇洋媚外	数典忘祖	数不胜数	光宗耀祖	B
讷言敏行	学无止境	敏而好学	义薄云天	C
老生常谈	故弄玄虚	世风日下	故伎重演	D
政通人和	政令不一	长治久安	一贫如洗	A
若即若离	敬而远之	月黑风高	敬若神明	B
卧薪尝胆	漫不经心	敷衍了事	趋炎附势	C
阳关大道	笑里藏刀	风雨飘摇	阳奉阴违	D
阳春白雪	虎落平阳	山重水复	高山流水	A
波云诡谲	阴阳怪气	稀奇古怪	阴阳两隔	B
顾此失彼	含冤负屈	邯郸学步	空乏其身	C
众目睽睽	格格不入	明镜高悬	隔墙有耳	D
阴魂不散	永垂不朽	势不可挡	阴差阳错	A
鹏程万里	随心所欲	相随心生	患得患失	B
剑走偏锋	清心寡欲	剑拔弩张	箭在弦上	C
多事之秋	深不可测	韬光养晦	别有用心	D
削足适履	牵强附会	削发明志	草木皆兵	A
为人师表	刎颈之交	口吻生花	同生共死	B
审时度势	夸夸其谈	刮目相看	推成出新	C

双管齐下	刚愎自用	貌美如花	刚柔并济	D
割据一方	分庭抗礼	割地求和	不计前嫌	A
舟车劳顿	彼竭我盈	彼众我寡	聚精会神	B
好逸恶劳	徒子徒孙	徒劳无功	口腹蜜饯	C
装腔作势	大腹便便	待人接物	待价而沽	D
徒有虚名	图谋不轨	芳名远播	浑然天成	A
有教无类	循循善诱	教导有方	循规蹈矩	B
一文不值	微言大义	微不足道	特立独行	C
不拘一格	枉费心机	以小搏大	徇私枉法	D
如鲠在喉	欲言又止	如临大敌	目中无人	A
悲痛欲绝	如丧考妣	家破人亡	如有神助	B
方兴未艾	如饥似渴	如日中天	紫气东来	C
红男绿女	不管不顾	始终如一	始乱终弃	D
始作俑者	先声夺人	当仁不让	始料不及	A
冷嘲热讽	嬉笑怒骂	嬉皮笑脸	摇笔即来	B
婀娜多姿	缓不济急	姗姗来迟	阳光明媚	C
文思泉涌	朝发夕至	妙不可言	妙手偶得	D
姹紫嫣红	花团锦簇	差强人意	善有善报	A
赴汤蹈火	肝脑涂地	肝胆相照	参差不齐	B
朝三暮四	变化无常	朝令夕改	莫名其妙	C
炙手可热	喜闻乐见	暗流涌动	脍炙人口	D
枕戈待旦	一触即发	枕流漱石	前车之鉴	A
天下大同	格物致知	格古通今	病入膏肓	B
束手无策	负隅顽抗	权宜之计	权衡利弊	C
同甘共苦	相敬如宾	秋后算账	相濡以沫	D
睹物思人	触景生情	有目共睹	淡泊名利	A
狼狈不堪	瞠目结舌	目瞪口呆	惨不忍睹	B
迷途知返	后顾之忧	瞻前顾后	进退维谷	C
时运不济	冯谖弹铗	四面楚歌	冯唐易老	D

Appendix E

Pre-Experimental Survey Questions

	Original Question	Translated Question
1	您的生日 (月/日/年):	Your birth date (MM/DD/YYYY):
2	您的年龄 (周岁):	Your age (years):
3	性别:	Gender:
4	请问您是: (右撇子/左撇子/双手):	Are you: (right-handed/left-handed/both)
5	您总共上了多少年学？ (比如，12=高中毕业)?	In total, how many years did you go to school? (e.g. 12=high school graduate)
6	请列出您会的所有语言:	Please list all the languages you speak:
7	如果超过一个，请问哪个是您的母语:	If you speak more than one language, please state your mother tongue:
8	对于您掌握的每一门语言，列举出您学习各语言的具体时长 (比如，西班牙语 - 3年):	For each language you mastered, list the specific length of time that you have studied each language (e.g. Spanish - 3 years):
9	请问您最经常说哪一种语言？ (比如，在家的时候)?:	Which language do you speak most often? (e.g. when at home)?:
10	与您的同龄人相比，您觉得您的身体状态如何? [1 = 差, 5 = 平均, 10 = 出色]:	Compared with your peers, how do you feel about your physical condition? [1 = poor, 5 = average, 10 = excellent]:
11	请问您有没有没有被矫正的听力或视力问题?	Do you have any hearing or vision problems that have been corrected?
12	请您描述一下您有哪种未矫正的听力与视力问题。	Please describe the kinds of uncorrected hearing and vision problems you may have.
13	请列举任何可能影响您认知行为的健康问题。这个健康问题可以是现在也可以是过去发生的（如果没有，请写无。）	Please list any health issues that may affect your cognitive behavior. This health problem can be current or in the past (if not applicable, please write none.)

Appendix F

Questions selected from the Language Experience and Proficiency Questionnaire (LEAP-Q)

	Question
1	Please list all the languages you know in order of dominance:
2	Please list all the languages you know in order of acquisition (your native language first):
3	Please list what percentage of the time you are currently and on average exposed to each language.
4	When choosing to read a text available in all your languages, in which percentage of cases would you choose to read it in each of your languages? Assume that the original was written in another language, which is unknown to you.
5	When choosing a language to speak with a person who is equally fluent in all your languages, what percentage of time would you speak each language? Please report percent of total time.
6	Please list the cultures with which you identify. On a scale of zero to ten, please rate the extent to which you identify with each culture. (Examples of possible cultures include US-American, Chinese, Jewish-Orthodox, etc.):
7	How many years of formal education do you have?
8	Have you ever had a vision problem, hearing impairment, language disability, or learning disability? If yes, please explain:
9	Age when you (1) began acquiring, (2) became fluent in, (3) began reading in, and (4) became fluent reading in [each language]?
10	Please list the number of years and months you spent in each language environment: a country where [insert language] is spoken, a family where [language] is spoken, and a school and/or working environment where [language] is spoken.
11	On a scale of 0 to 10, select your level of proficiency in speaking, understanding, and reading.

Appendix G

Post-Experimental Survey Questions

	Original Question	Translated Question
1	请问您注意到您评估过频率的词语与成语问题的答案之间的任何关系吗?	Did you notice any relationship between the words for which you have assessed the frequency and the answers to the cheng-yu question?
2	如果没有，您认为看到需要评估的词语的意义是什么?	If not, why do you think you saw the words that you needed to evaluate?
3	如果您注意到了某种关系，您可以解释它具体是什么吗?	If you noticed a relationship, can you explain what it is?
4	请问您是否记得具体是哪一个词语让您意识到了这层关系?	Do you remember the specific word that made you aware of this relationship?
5	请问您是在实验的那一个时刻第一次意识到这层关系（比如实验开始的五分钟后）?	At which moment did you realize this relationship (for example, five minutes after the experiment started)?
6	请问多久您会注意到一层关系（一次，五次，等等）?	How often do you notice a relationship (once, five times, etc.)?
7	请问您是在什么阶段注意到这一层关系的呢? 是当您看到需要评估的词语时，还是看完所有的词语后，还是在看到第二次出现的成语问题时，还是实验最后的某个时刻? （请尽量的具体）	At what stage did you notice this relationship? Was it when you saw the words that needed to be evaluated, or after reading all the words, or when you saw the cheng-yu being presented again, or at some point at the end of the experiment? (Please be as specific as possible)
8	请问您有没有试图使用您看到的任何词语来试着回忆起成语问题的答案?	Did you try to use any of the words you saw to recall the answer to the cheng-yu question?
9	如果有，您能提供一个具体的例子吗?	If you did, can you provide a specific example?
10	请问您能解释您具体是如何做到的呢? 您的策略是什么?	Can you explain how you did it? What was your strategy?
11	请问您在多少道题上使用了这个策略（一次，五次，等等）? （如果您不确定具体有多少请试着估算）	On how many questions did you use this strategy (once, five times, etc.)? (If you are not sure how much, please try to estimate)
12	请问您在使用这个策略后是否有成功的回忆起成语? 如果有，多少次（一次，五次，等等）?	Do you recall the cheng-yu successfully after using this strategy? If so, how many times (once, five times, etc.)?