The Mechanism of Aging in Chinese Picture Naming: The Influence of Non-selective Inhibitory Ability

Authors: Yang Qun, Zhang Qingfang, Zhang Qingfang

Date: 2019-06-25T00:00:00+00:00

Abstract

This study employed a picture-word interference task to investigate and compare the distractor frequency effect in spoken word production in Chinese between young and older adults, as well as the impact of non-selective inhibitory ability on the distractor frequency effect and picture naming latency in both groups. The results revealed that the frequency of unrelated distractor words influenced the picture naming process in young adults, producing a distractor frequency effect that likely occurred at the response exclusion stage and was not modulated by non-selective inhibitory ability. In contrast, no distractor frequency effect was observed in older adults, possibly attributable to degraded phonological representations in the elderly that prevented them from utilizing distractor word frequency information, thereby supporting the transmission deficit hypothesis of cognitive aging in spoken production. Non-selective inhibitory ability affected picture naming latency in the picture-word interference task for older adults; diminished non-selective inhibitory ability resulted in prolonged picture naming times, indicating that declines in general cognitive abilities influence the language production process.

Full Text

Aging Mechanisms in Chinese Picture Naming: The Influence of Non-Selective Inhibition Ability

YANG Qun, ZHANG Qingfang
Department of Psychology, Renmin University of China, Beijing 100872

Abstract

This study employed a picture-word interference task to investigate and compare distractor word frequency effects in young and older adults during Chinese spoken word production, and to examine how non-selective inhibition ability influences these effects and picture naming latencies in both age groups. The results revealed that irrelevant distractor word frequency affected young adults' picture naming processes, producing a distractor frequency effect that likely occurs during the response exclusion stage and is not influenced by non-selective inhibition ability. In contrast, no distractor frequency effect was observed in older adults, possibly due to degraded phonological representations preventing them from utilizing distractor frequency information. This finding supports the transmission deficit hypothesis of cognitive aging in speech production. Non-selective inhibition ability significantly affected picture naming latencies in older adults: weaker non-selective inhibition capacity led to longer naming times, indicating that declines in general cognitive abilities impact language production processes.

Keywords: aging of speech production; picture-word interference task; distractor frequency effect; word frequency effect; non-selective inhibition

1. Introduction

Language production refers to the psychological process by which people express thoughts through language, involving the conversion from conceptual codes to linguistic codes and then to physiological and motor codes—using vocal organs for speech production or writing organs for written production. Spoken word production comprises conceptual preparation, lexical selection, phonological encoding, phonetic encoding, and articulation. The classic paradigm for studying spoken word production is the picture-word interference task (PWI), in which pictures and distractor words are presented simultaneously. Participants are instructed to ignore the distractor words and name the pictures as accurately and quickly as possible. Researchers have found that when semantic distractors belong to the same semantic category as the target name, they significantly prolong picture naming times compared to unrelated distractors—an effect known as semantic interference (Glaser & Düngelhoff, 1984; Schriefers, Meyer, & Levelt, 1990; Starreveld & La Heij, 1996). When using unrelated distractors in the PWI paradigm, researchers have observed that naming times are faster with high-frequency than low-frequency unrelated distractors (Miozzo & Caramazza, 2003), termed the distractor frequency effect. These two effects play important roles in theoretical models of lexical selection in spoken word production.

1.1 Lexical Selection Mechanisms: Competitive and Non-Competitive Accounts

In response to semantic interference effects observed in the PWI paradigm, researchers proposed the lexical selection competition hypothesis, which assumes that target word selection depends not only on the activation level of the target itself but also on the activation levels of other competing words. The higher the activation level of competing words, the longer the time required for target selection. Cutting and Ferreira (1999) argued that non-target words influence target selection through inhibitory connections among lexical entries in the mental lexicon—all activated words mutually inhibit each other, with the most strongly activated lexical node exerting the strongest inhibition on others. When a word's activation reaches threshold, that word is selected as the target. Semantic interference effects provide supporting evidence for the competitive account (Glaser & Düngelhoff, 1984; Schriefers, Meyer, & Levelt, 1990; Starreveld & La Heij, 1996; Zhu, Damian, & Zhang, 2015; Zhu, Zhang, Damian, 2016).

An alternative theoretical perspective opposing the competition hypothesis is the non-competitive account of lexical selection, which holds that the most highly activated word is selected as the target regardless of other simultaneously activated words. The most prominent version of this view is the Response Exclusion Hypothesis (REH), which posits that conflict between target and distractor occurs in the response output buffer—that is, at a post-lexical level rather than during lexical selection. According to this view, activation among lexical entries facilitates rather than inhibits each other (Finkbeiner & Caramazza, 2006; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). Mahon et al. theorized that the response output buffer can hold only one response at a time. In the PWI task, distractor words gain priority access to the response buffer and must be cleared before the target can be articulated. This process is closely related to the distractor' s "response relevance," which determines how long it takes to clear the buffer. Compared to unrelated conditions, semantically related distractors have higher response relevance and thus require more time to be excluded from the buffer, producing semantic interference effects. The REH therefore locates semantic interference effects observed in the PWI task at the post-lexical level in the response buffer.

The distractor frequency effect provides supporting evidence for the REH (Miozzo & Caramazza, 2003; Dhooge & Hartsuiker, 2010). Miozzo and Caramazza (2003) found a distractor frequency effect and examined whether it interacted with phonological and semantic relatedness. They found different time courses for semantic interference and distractor frequency effects, suggesting these effects occur at different levels of lexical access—semantic processing for the former and lexical node selection for the latter. The researchers found an interaction between distractor frequency and phonological relatedness, suggesting these two effects may occur at the same stage of spoken word production: phonological encoding. According to competition theory, since high-frequency words are more activated than low-frequency words, high-frequency distractors should produce stronger competition with the target than low-frequency distractors—yet the results showed the opposite pattern. From the REH perspective, Miozzo and Caramazza (2003) argued that in the PWI task, speakers do not first select the target word but must first inhibit the interfering distractor word. One factor affecting target naming time is how quickly the distractor can be inhibited. At the response output stage, inhibition of low-frequency distractors is slower than for high-frequency distractors. Although high- and low-frequency distractors are equally unrelated to the target and thus have equivalent response relevance, high-frequency words are recognized and processed faster than low-frequency words, reaching the response buffer earlier. Consequently, they are inhibited and excluded from the buffer more quickly, producing faster response times in the high-frequency unrelated distractor condition.

Proponents of the competition account (Roelofs, Piai, & Schriefers, 2010) argue that critics have failed to consider attentional mechanisms within the competition framework, focusing only on lexical production processes in the PWI paradigm. When selective attention mechanisms are incorporated, the competition hypothesis can also explain the distractor frequency effect. In the PWI paradigm, after initial processing of the picture and distractor, attentional mechanisms inhibit the distractor while increasing activation of the target word (Duncan, 2004). The speed of distractor inhibition depends on how quickly distractor information (form encoding) is accessed (Protopapas, Archonti, & Skaloumbakas, 2007). For high- and low-frequency unrelated distractors, high-frequency words are processed faster than low-frequency words, so attentional mechanisms operate earlier and more quickly on high-frequency words, thereby reducing their impact on picture naming within the competition framework. Roelofs (2005) simulated the effect of word frequency on picture naming through computer modeling, producing results consistent with existing distractor frequency effect data (Miozzo & Caramazza, 2003). Thus, a revised competition hypothesis incorporating attentional modulation can also account for the distractor frequency effect.

1.2 Cognitive Aging in Speech Production

Most language production research has used young adults or university students (typically under 35 years old), with few studies focusing on older adults. Older adults exhibit declines in general cognitive abilities such as working memory, processing speed, inductive reasoning, and even lexical abilities—a phenomenon known as cognitive aging (Schaie, 2000). Similar to memory and other cognitive processes, human language production abilities also decline with age (Burke & Shafto, 2008), possibly due to declines in general cognitive abilities. Research indicates that cognitive aging in speech production occurs at the phonological encoding stage (Mortensen, Meyer, & Humphreys, 2006). Older adults experience more tip-of-the-tongue phenomena than young adults, suggesting they know the word they want to express but cannot successfully retrieve its pronunciation, indicating difficulty at the phonological encoding stage of spoken word production (Burke, MacKay, Worthley, & Wade, 1991).

In Chinese spoken word production, Yang and Zhang (2015) found that older adults had longer picture naming times than young adults, with larger word frequency and syllable frequency effects in older adults. Additionally, older adults showed an interaction between word frequency and syllable frequency, whereas young adults did not, indicating that information interaction patterns change with age. Compared to young adults, older adults experience more character writing blocks in writing. MacKay and Abrams (1998) found that when words were presented auditorily, older adults were more likely than young adults to produce spelling errors. When asked to judge whether visually presented words were spelled correctly, both groups showed equivalent accuracy, but when asked to write the words they had just seen, older adults produced more spelling errors (MacKay, Abrams, & Pedroza, 1999). These results suggest that access to orthographic representations weakens with age, possibly due to weaker connections between orthographic and phonological representations in older adults (Burke et al., 1991)—a phenomenon termed the Transmission Deficit Hypothesis (TDH). This hypothesis posits that aging in speech production is language-specific, related to characteristics of the language itself.

The TDH was proposed within the theoretical framework of the competition hypothesis. Researchers argue that older adults' semantic interference effects occur during lexical selection and are comparable to those of young adults, occurring at the lexical selection stage rather than the response exclusion stage. Cognitive aging in speech production primarily manifests as reduced phonological activation strength compared to young adults, resulting from weakened connections between semantic activation at the lemma selection stage and phonological activation at the phonological encoding stage. Other researchers propose that cognitive aging in language production may result from older adults' reduced ability to inhibit interfering information—the Inhibition Hypothesis—which attributes aging effects to declines in general cognitive abilities and is thus language-non-specific.

Current research on distractor frequency effects has focused on Indo-European languages. Studies indicate that connection patterns between semantic and phonological nodes during spoken word production show cross-linguistic variation. In Chinese word production, the time course of semantic and phonological information activation is serial: semantic information is activated first, followed by phonological information, with no mutual influence between the two types of activation (Zhu, Damian, & Zhang, 2015; Zhu, Zhang, & Damian, 2016; Zhang, Zhu, & Damian, 2018). In alphabetic languages like English, however, the time courses of semantic and phonological activation overlap, with mutual influences between the two types of information and feedback from phonological activation to semantic nodes (Starreveld & La Heij, 1995; Dell' Acqua et al., 2010). Compared to alphabetic languages, connections between semantic and phonological nodes may be weaker in Chinese, resulting in different patterns of relationship between semantic and phonological processing across languages. These different patterns may lead to variations in the manifestation of distractor frequency effects, which may be jointly influenced by spoken word production patterns and attentional mechanisms in different languages.

In summary, the competition hypothesis posits that the distractor frequency effect occurs during lemma selection (including lexical selection and phonological encoding), with attentional mechanisms playing an important role. The non-competitive hypothesis locates this effect at the response output stage. Theories of cognitive aging in speech production suggest that aging manifests as weakened connections between lemma selection and phonological encoding processes (language-specific aging) or as reduced ability to inhibit interfering information (language-non-specific aging). No previous research has investigated whether the distractor frequency effect in Chinese spoken word production shows age-related changes. The present study used the picture-word interference paradigm to examine whether and how distractor frequency effects occur in Chinese spoken word production and their cognitive aging mechanisms. Experiment 1 investigated and compared distractor frequency effects and their time courses in young and older adults. Experiment 2 examined whether non-selective inhibition ability affects picture naming processes in the PWI paradigm for both age groups.

2. Experiment 1

2.1.1 Participants

Twenty-five undergraduate and graduate students (ages 19–28 years, 7 male, mean age 23.2 years) with a mean education level of 16.2 years participated, along with twenty-four retired researchers with undergraduate degrees or higher (ages 63–79 years, 10 male, mean age 68.5 years) with a mean education level of 15.8 years. All participants had normal or corrected-to-normal vision and were right-handed native speakers of Northern Standard Mandarin. Prior to the experiment, older adults were screened using the Chinese version of the Montreal Cognitive Assessment Scale (MoCA) to select participants (see Castro & James, 2014; Sörös, Bose, Sokoloff, Graham & Stuss, 2011). Older adults with MoCA scores below 26 were excluded. The mean MoCA score was 27.5 (range 26–30), indicating normal cognitive function.

2.1.2 Materials

Fifty-four black-and-white line drawings were selected from the standardized picture database established by Zhang and Yang (2003), including 2 practice pictures and 52 experimental pictures. The selected target picture names varied in word frequency: 15 high-frequency words (frequency $>$ 130 per million), 22 medium-frequency words (47 $<$ frequency $<$ 130 per million), and 15 low-frequency words (frequency $<$ 47 per million). Each picture was paired with two distractor characters: one high-frequency Chinese character (frequency $>$ 130 per million) and one low-frequency character (frequency $<$ 47 per million). Distractor characters were unrelated to target characters in phonology or semantics, yielding 104 distractor characters total. High- and low-frequency distractor characters were matched for stroke count, with both groups averaging 9.62 strokes.

2.1.3 Design

The independent variables included age (young vs. older), distractor character frequency (high vs. low), and stimulus onset asynchrony (SOA) between target pictures and distractor characters, which had three levels: -100 ms (distractor preceded picture by 100 ms), 0 ms (simultaneous presentation), and +100 ms (picture preceded distractor by 100 ms). Distractor frequency and SOA were within-subjects variables, while age was a between-subjects variable. The 52 target pictures were paired with unrelated high-frequency and low-frequency distractor characters, creating 104 picture-distractor pairs. The formal experiment was completed in three blocks, each with a fixed SOA value. Each block contained 104 trials, with each picture presented twice. Trials were pseudo-randomized to prevent consecutive presentation of identical pictures. The order of the three blocks was fully counterbalanced across participants using a Latin square design. Each participant completed 312 trials across the three SOA conditions. Practice trials corresponding to each SOA condition preceded each block.

2.1.4 Apparatus

The experiment was programmed using E-Prime. A PST-SRBOX response box, microphone, and computer were used. Pictures were presented at the center of a PIII-667 computer screen. Participants' responses were recorded via a microphone connected to the response box. All stimulus presentation, timing, and response time collection were computer-controlled.

2.1.5 Procedure

Before the formal experiment, each picture and its corresponding name were presented sequentially at the center of the screen for 2 seconds each (54 pictures total). Participants were informed that these pictures would appear in the formal experiment and were asked to memorize the corresponding names. If participants misnamed a picture, they were corrected and reminded to remember the correct name. Generally, because these were common pictures with high naming consistency, participants' naming matched the names provided by the program.

During the formal experiment, a fixation cross "+" appeared at the center of the screen for 500 ms, followed by a blank screen for 500 ms. The picture and distractor character were then presented simultaneously or with a temporal offset, with the distractor character positioned at the center of the picture. Participants were instructed to ignore the distractor character and name the picture as accurately and quickly as possible. The picture and distractor disappeared when the participant responded, and the experimenter judged the response accuracy. The next trial began after a 1000 ms interval. The computer recorded response times. The entire experiment lasted approximately 30 minutes.

2.2 Results

For response time data, trials with response times below 300 ms or above 2500 ms, as well as data points beyond 2.5 standard deviations from the mean, were excluded. At SOA = -100 ms, 171 data points were excluded (4.72% of total data). At SOA = 0 ms, 177 data points were excluded (4.88%). At SOA = +100 ms, 177 data points were excluded (5.38%). Table 1 shows mean response times and effect sizes for the distractor frequency effect in young and older adults across different SOAs.

Table 1 Mean Picture Naming Latencies (SD) in ms for Young and Older Adults Across SOA and Distractor Frequency Conditions

Age Group	SOA (ms)	Low-Frequency Distractor	High-Frequency Distractor	Effect Size (Low-High)	Cohen's d
Young	-100	702 (64)	691 (57)	11	0.18
	0	712 (85)	691 (74)	21	0.27
	+100	588 (70)	580 (60)	8	0.12
Older	-100	847 (128)	842 (121)	5	0.04
	0	827 (114)	825 (118)	2	0.02
	+100	725 (121)	734 (106)	-9	-0.08

- $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Response time analysis revealed a significant main effect of distractor frequency, F (1,47) = 6.11, p = 0.017, MSE = 626.12, ^{2} = 0.12; F (1,108) = 5.03, p = 0.027, MSE = 909.38, ^{2} = 0.04. The main effect of age was significant, F (1,47) = 26.04, p < 0.001, MSE = 46576.79, ^{2} = 0.36; F (1,108) = 387.32, p < 0.001, MSE = 4762.55, ^{2} = 0.78. The main effect of SOA was significant, F (2,47) = 7.21, p < 0.001, MSE = 3067.17, ^{2} = 0.80; F (2,108) = 23.09, p < 0.001, MSE = 24967.22, ^{2} = 0.30. The three-way interaction between distractor frequency, age, and SOA was marginally significant in the participant analysis but not in the item analysis, F (2,47) = 3.19, p = 0.080, MSE = 301.29, ^{2} = 0.06; F (2,108) = 1.18, p = 0.312, MSE = 771.76, ^{2} = 0.02. Other interactions were not significant (ps > 0.05). To further examine the relationship among distractor frequency, age, and SOA, simple-simple effect analyses were conducted to investigate the distractor frequency × age interaction at each SOA.

At SOA = -100 ms, the main effect of distractor frequency was significant, F (1,47) = 7.21, p = 0.010, MSE = 345.75, ^{2} = 0.13; F (1,36) = 4.74, p = 0.036, MSE = 642.09, ^{2} = 0.12. The main effect of age was significant, F (1,47) = 24.22, p < 0.001, MSE = 16217.69, ^{2} = 0.34; F (1,36) = 127.76, p < 0.001, MSE = 4605.31, ^{2} = 0.78. The distractor frequency × age interaction was not significant, F (1,47) = 0.01, p = 0.923, MSE = 345.75, ^{2} < 0.01; F (1,36) = 0.001, p = 0.98, MSE = 718.76, ^{2} < 0.01.

At SOA = 0 ms, response time ANOVA revealed a significant main effect of distractor frequency, F (1,47) = 7.91, p = 0.007, MSE = 496.52, ^{2} = 0.14; F (1,36) = 6.55, p = 0.015, MSE = 762.89, ^{2} = 0.15. The main effect of age was significant, F (1,47) = 19.48, p < 0.001, MSE = 19594.70, ^{2} = 0.29; F (1,36) = 138.18, p < 0.001, MSE = 4174.44, ^{2} = 0.78. The distractor frequency ×

age interaction was not significant, F (1,47) = 0.01, p = 0.923, MSE = 496.52, ^{2} < 0.01; F (1,36) = 0.159, p = 0.692, MSE = 780.45, ^{2} < 0.01.

At SOA = +100 ms, response time ANOVA revealed no significant main effect of distractor frequency, F (1,47) = 0.08, p = 0.777, MSE = 371.11, ^{2} = 0.002; F (1,36) = 0.06, p = 0.811, MSE = 1323.17, ^{2} = 0.002. The main effect of age was significant, F (1,47) = 27.08, p < 0.001, MSE = 16240.58, ^{2} = 0.37; F (1,36) = 123.83, p < 0.001, MSE = 5507.89, ^{2} = 0.78. The distractor frequency × age interaction was significant, F (1,47) = 4.76, p = 0.034, MSE = 371.11, ^{2} = 0.09; F (1,36) = 4.03, p = 0.052, MSE = 816.03, ^{2} = 0.10.

Picture naming error rates were less than 1%, so no further ANOVA was conducted on error rates.

To quantify the magnitude of the distractor frequency effect, Cohen' s d values were calculated to compare effect sizes between young and older adults (see Table 1). Cohen' s d is an index of effect size magnitude (Snyder & Lawson, 1993) that is relatively independent of sample size and allows for comparisons across different participant populations (Zheng, Wen, & Wu, 2011). A Cohen' s d between 0.2 and 0.5 indicates a small effect, between 0.5 and 0.8 a medium effect, and above 0.8 a large effect (Cohen, 1988). The results showed that young adults' distractor frequency effect was small (d = 0.38), while older adults' effect sizes were all below 0.2.

The primary finding of Experiment 1 was that young adults showed significant distractor frequency effects at SOAs of -100 ms and 0 ms, with the largest effect size when pictures and distractors were presented simultaneously—consistent with previous research (Miozzo & Caramazza, 2003; Dhooge & Hartsuiker, 2010). This indicates that a distractor frequency effect similar to that in Indo-European languages also exists in Chinese spoken word production. In contrast, older adults showed no distractor frequency effect at any SOA level.

We hypothesize two possible reasons for this absence in older adults. First, as general inhibitory abilities decline with age, the capacity to use attentional mechanisms to regulate speech production may weaken, making high- and low-frequency unrelated distractors equally impactful on picture naming, thus eliminating the distractor frequency effect. Researchers have distinguished between selective and non-selective inhibition (Forstmann et al., 2008). Non-selective inhibition includes top-down inhibition of planned responses and the ability to handle any unexpected responses, typically measured by the stop-signal task, reflecting individuals' ability to inhibit prepared responses. Selective inhibition refers to top-down inhibition of responses that strongly compete with target responses, typically measured by Stroop, Simon, and Flanker tasks (Nigg, 2000). Shao et al. (2013) used the PWI paradigm and stop-signal task to examine the relationship between selective and non-selective inhibition and how these abilities affect picture naming speed. They found that non-selective inhibition ability significantly correlated with average picture naming latencies but not with selective inhibition measures or semantic interference effect sizes, suggesting that selective inhibition of competing information and non-selective inhibition in picture naming tasks are somewhat dissociated (Shao, Meyer, & Roelofs, 2013).

Second, target picture word frequency might influence the distractor frequency effect. Previous research on Chinese spoken and written production has found that target picture word frequency affects picture naming processes (Yang & Zhang, 2015; He & Zhang, 2017; Zhang & Wang, 2014), with faster retrieval times for high-frequency than low-frequency target words, producing a target word frequency effect. Speakers' picture naming processes are thus sensitive to target picture name frequency, with older adults showing significantly larger target word frequency effects (low-frequency minus high-frequency) than young adults, demonstrating language-specific cognitive aging. In the PWI task, when unrelated distractors are presented, speakers process both distractors and targets. As noted, access speed for both distractors and targets is influenced by frequency information. In English spoken word production, Miozzo and Caramazza (2003) found that target word frequency and distractor frequency operated independently without interaction. However, no research has examined whether these two variables interact in Chinese. Thus, attentional modulation ability, target word frequency, and distractor frequency may jointly influence the distractor frequency effect in older adults' spoken word production. Although Experiment 1 reported word frequency information for target pictures, the number of target pictures at each frequency level was not matched.

Experiment 2 manipulated target word frequency and, following Shao et al.' s (2013) methodology, used the stop-signal task to measure non-selective inhibition ability in both young and older adults to examine the relationship between non-selective inhibition and the distractor frequency effect and their influence on speech production processes.

3. Experiment 2

3.1.1 Participants

Twenty-five university students and graduate students (ages 18–30 years, 7 male, mean age 23.28 years) with a mean education level of 16.96 years (range 13–22 years) participated, along with thirty-eight older adults over 60 years old (ages 63–79 years, 17 male, mean age 69.13 years) with a mean education level of 13.0 years (range 8-17 years). Prior to the experiment, older adults were screened using the Chinese version of the Montreal Cognitive Assessment Scale (MoCA). Only older adults with MoCA scores above 26 and normal cognitive function were selected. The mean MoCA score for the 38 older adults was 26.8.

3.1.2 Materials

Sixty-two black-and-white line drawings were selected from the standardized picture database established by Zhang and Yang (2003), including 2 practice pictures and 60 experimental pictures. The selected target picture names varied in word frequency: 20 high-frequency words (frequency > 130 per million), 20 medium-frequency words (47 < frequency < 130 per million), and 20 low-frequency words (frequency < 47 per million). The three groups of target picture names did not differ significantly in stroke count or component number, $F(2,57) = 0.06$, $p = 0.943$ for stroke count; $F(2,57) = 2.15$, $p = 0.126$ for component number. Each picture was paired with two distractor characters: one high-frequency Chinese character (frequency > 130 per million) and one low-frequency character (frequency < 47 per million). Distractor characters were unrelated to target characters in phonology, semantics, or orthography, yielding 120 distractor characters total. High- and low-frequency distractor characters were matched for stroke count, with both groups averaging 9.57 strokes.

3.1.3 Design

The independent variables included age (young vs. older), distractor character frequency (high vs. low), and target picture name frequency (high, medium, and low). Distractor frequency and target word frequency were within-subjects variables, while age was a between-subjects variable. The 60 target pictures were paired with unrelated high-frequency and low-frequency distractor characters, creating 120 picture-distractor pairs. Each picture was presented twice. Trials were pseudo-randomized to prevent consecutive presentation of identical pictures.

3.1.4 Apparatus

The apparatus was identical to Experiment 1.

3.1.5 Procedure

The experiment consisted of two parts. The first part used the stop-signal task to measure each participant’ s non-selective inhibition ability (Roelofs, Piai & Rodriguez, 2011). The second part was a picture naming task under the picture-word interference paradigm, with identical procedures and stimulus presentation to Experiment 1.

The stop-signal task comprised a go task and a stop task (Logan, 1994). In the go task, a fixation cross “+” appeared at the center of the screen for 250 ms, followed by a blank screen for 250 ms, after which a 1 cm square or 1 cm diameter circle appeared at the center. Participants were instructed to press the “F” key for squares and the “J” key for circles. The shape remained on screen for a maximum of 1250 ms, with all participants using matched left-right hand responses. The stop-signal task built upon the go task: after a shape appeared, participants might hear a 75 ms, 750 Hz auditory tone, which signaled them to withhold their response for that trial. The initial stop-signal delay (SSD) between shape onset and the tone was 250 ms. If participants successfully inhibited their response, the SSD increased by 50 ms on the next trial to increase inhibition difficulty; otherwise, it decreased by 50 ms.

The go task measured choice reaction time, while the stop task required participants to inhibit a prepared response upon hearing the stop signal. The interval between the stop signal and the choice reaction task was determined by participants' performance on the previous stop trial. The stop-signal task program consisted of two phases: a practice phase with one block of 32 trials and a test phase with three blocks of 64 trials each. The ratio of go to stop trials in each block was 3:1, presented randomly. Non-selective inhibition ability was indexed by the stop-signal reaction time, calculated as the difference between mean reaction time in go trials and mean SSD (Verbruggen, Logan, & Stevens, 2008).

3.2 Results

In young adults, 41 error trials were excluded (1.49% of total). Trials with response times below 300 ms or above 2500 ms, plus trials beyond 2.5 standard deviations, totaled 109 trials (3.95% of data). In older adults, 77 error trials were excluded (1.69%). Trials with response times below 300 ms or above 2500 ms, plus trials beyond 2.5 standard deviations, totaled 149 trials (3.27%). Table 2 shows mean response times and standard deviations for each condition.

Table 2 Mean Response Times (ms) and Standard Deviations for Young and Older Adults Across Conditions

Age Group	Target Word Frequency	Low-Frequency Distractor	High-Frequency Distractor	Cohen' s d (Low-High)
Young	High	752 (98)	742 (96)	0.10
	Medium	762 (99)	750 (91)	0.13
	Low	731 (99)	703 (92)	0.29***
Older	High	854 (86)	841 (73)	0.16
	Medium	856 (87)	857 (76)	-0.01
	Low	812 (93)	809 (79)	0.04

- $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 3 shows the ANOVA results for the three independent variables of age, target word frequency, and distractor word frequency. The three-way interaction was significant in the participant analysis but not in the item analysis. We further analyzed the target word frequency × distractor frequency interaction separately for young and older adults.

Table 3 ANOVA Results for Response Times by Age, Target Word Frequency, and Distractor Frequency

Effect	Participant Analysis	Item Analysis
Target Word Frequency	$F(2, 122) = 42.13$, $p < .001$	$F(2, 114) = 3.95$, $p = .022$

Effect	Participant Analysis	Item Analysis
Distractor Frequency	F (1, 61) = 27.43, p < .001	F (1, 114) = 13.97, p < .001
Age × Distractor Frequency	F (1, 61) = 15.21, p < .001	F (1, 114) = 7.12, p = .009
Age × Distractor × Target Frequency	F (2, 122) = 3.15, p = .046	F (2, 114) = 1.21, p = .301

For young adults, the main effect of target picture word frequency was significant in the participant analysis but not in the item analysis, F (2,48) = 21.71, p < 0.001, MSE = 958.11, ^{2} = 0.48; F (2,57) = 2.30, p = 0.110, MSE = 7852.42, ^{2} = 0.08. The distractor frequency effect was significant, F (1,24) = 26.57, p < 0.001, MSE = 405.07, ^{2} = 0.53; F (1,57) = 13.31, p = 0.001, MSE = 760.14, ^{2} = 0.19. The interaction between target picture frequency and distractor frequency was not significant, F (2,48) = 2.39, p = 0.102, MSE = 560.02, ^{2} = 0.09; F (2,57) = 1.36, p = 0.265, MSE = 760.14, ^{2} = 0.05. Thus, young adults' distractor frequency effect was not influenced by target picture word frequency.

For older adults, the main effect of target word frequency was significant in the participant analysis but not in the item analysis, F (2,36) = 22.42, p < 0.001, MSE = 1812.90, ^{2} = 0.56; F (2,57) = 1.65, p = 0.201, MSE = 15649.93, ^{2} = 0.06. The distractor frequency effect was not significant, F (1,37) = 0.86, p = 0.358, MSE = 1374.24, ^{2} = 0.02; F (1,57) = 0.66, p = 0.420, MSE = 49751.04, ^{2} = 0.01. The interaction between target picture frequency and distractor frequency was not significant, F (2,36) = 1.15, p = 0.329, MSE = 1371.51, ^{2} = 0.06; F (2,57) = 0.85, p = 0.432, MSE = 49751.04, ^{2} = 0.03.

Older adults' non-selective inhibition ability (M = 178 ms, SD = 99 ms, range: -4 ms to 398 ms) was weaker than that of young adults (M = 100 ms, SD = 124 ms, range: -107 ms to 291 ms), with a significant difference between groups, F(1,62) = 7.75, p = 0.007, d = 0.35, indicating that older adults required more time to inhibit responses. To examine whether non-selective inhibition ability affected picture naming processes, Pearson correlation coefficients were calculated separately for each age group between non-selective inhibition ability and mean picture naming latencies. For young adults, non-selective inhibition ability was not significantly correlated with mean response times in the PWI task, r = -0.042, p = 0.841. For older adults, this correlation was significant, r = 0.338, p = 0.038. Neither age group showed significant correlations between non-selective inhibition ability and the magnitude of the distractor frequency effect (young: r = 0.303, p = 0.140; older: r = 0.058, p = 0.732). Figure 1 [Figure 1: see original paper] shows scatter plots of the relationship between non-selective inhibition ability and mean picture naming latencies for both age groups.

To determine which variables significantly predicted older adults' picture naming times when simultaneously considering age, education level, general cognitive ability (MoCA), and non-selective inhibition ability, regression analysis was conducted. Table 4 shows the results. Only the standardized coefficient for non-selective inhibition ability was significant, with a 95% CI of [-0.01, 0.48], indicating that non-selective inhibition ability significantly predicted older adults' picture naming times.

Table 4 Regression Analysis of Age, Education, General Cognitive Ability, and Non-Selective Inhibition Ability on Older Adults' Mean Picture Naming Latencies

Predictor		SE	t	p	95% CI
Age	0.12	0.08	1.50	0.14	[-0.04, 0.28]
Education	-0.08	0.05	-1.60	0.12	[-0.18, 0.02]
MoCA	-0.05	0.03	-1.67	0.10	[-0.11, 0.01]
Non-selective Inhibition	0.23	0.11	2.09	0.04*	[0.01, 0.45]

- $p < 0.05$

3.3 Discussion

Experiment 2 yielded three main findings. First, both young and older groups showed the classic target word frequency effect, indicating that speakers are highly sensitive to target word frequency. Previous picture naming studies have consistently demonstrated target word frequency effects (Zhang & Wang, 2014; Yang & Zhang, 2015). Second, after manipulating target word frequency, the distractor frequency effect remained significant only in the young group. The results from Experiments 1 and 2 consistently showed that young adults' distractor frequency effects were small (Cohen' s d = 0.38 or 0.29), while older adults' effect sizes were all below 0.2, indicating a weak but present distractor frequency effect in young adults and an absent effect in older adults. Neither age group showed a significant interaction between target word frequency and distractor frequency, consistent with findings from alphabetic languages (Miozzo & Caramazza, 2003) and suggesting that these two variables operate independently in young adults. Third, older adults' mean picture naming latencies were significantly longer than young adults' , and their non-selective inhibition ability was weaker. Non-selective inhibition ability correlated significantly with picture naming latencies in older adults but not in young adults. However, non-selective inhibition ability did not correlate significantly with the magnitude of the distractor frequency effect in either age group. These results indicate that declines in non-selective inhibition ability affect language production speed.

Shao et al. (2013) examined relationships between picture naming latencies and selective and non-selective inhibition abilities in speakers aged 16 to 63 years.

They found that non-selective inhibition ability, measured by the stop-signal task, significantly correlated with mean picture naming latencies in the PWI task but not with semantic interference effect magnitude. Our older adult results replicate Shao et al.'s findings, though young adults'non-selective inhibition ability did not affect picture naming latencies in our study. This may be due to our narrow age range for young adults, resulting in limited variation in naming latencies and thus no significant correlation. Older adults' average naming latencies were 800 ms (Experiment 1) and 838 ms (Experiment 2), substantially longer than young adults' 677 ms (Experiment 1) and 740 ms (Experiment 2). This likely reflects both general cognitive declines (Schaie, 2000) and language production deficits (Burke et al., 1991) associated with aging. Although MoCA scores indicated normal cognitive function for older adults, this does not rule out potential influences from changes in general cognitive abilities (working memory, attention, motor execution) and language processing capacities (e.g., vocabulary size). Future research should examine relationships among selective inhibition, non-selective inhibition, and picture naming latencies across the full adult lifespan (ages 18–80).

Correlations between stop-signal task response times and distractor frequency effect magnitude were not significant in either age group. This suggests that for unrelated distractors, non-selective inhibition ability affects high- and low-frequency distractors equivalently. Shao et al. (2013) examined relationships between semantic interference effects and non-selective inhibition ability in Dutch picture naming. Semantic interference effects compare semantically related versus unrelated distractors. They found no significant correlation between non-selective inhibition ability and semantic interference magnitude, concluding that non-selective inhibition is indeed non-selective—it affects semantically related and unrelated distractors equally. Similarly, our study found that non-selective inhibition ability affected overall picture naming processes but not the magnitude of the distractor frequency effect.

4. General Discussion

Using the picture-word interference task, two experiments investigated and compared distractor frequency effects in young and older adults during Chinese spoken word production and explored how non-selective inhibition ability affects these effects and picture naming latencies. The main findings were: (1) Both age groups showed classic target word frequency effects; (2) Distractor frequency effects were found only in young adults, not in older adults, with no interaction between distractor frequency and target word frequency in either group; (3) Non-selective inhibition ability affected picture naming latencies in older adults but did not influence the distractor frequency effect in either group.

The consistent presence of distractor frequency effects in young adults across Experiments 1 and 2 indicates that young adults can utilize distractor word frequency information in the PWI task. According to the REH, this effect likely occurs at the post-lexical stage—specifically, the response exclusion stage.

When distractors are presented, high-frequency words are recognized and processed faster than low-frequency words, reaching the response buffer earlier. Consequently, they are inhibited and excluded from the buffer more quickly, producing the distractor frequency effect. Both age groups showed target word frequency effects, indicating that word frequency information strengthened activation of high-frequency target words, resulting in faster naming. Research suggests that word frequency effects occur at lexical selection or phonological encoding stages (Jescheniak & Levelt, 1994; Stemberger & MacWhinney, 1986; Jescheniak, Meyer, & Levelt, 2003)—that is, at lexical-level processing. Qu et al. (2016) found that target word frequency effects in Chinese written production emerged 200 ms after picture onset, indicating lexical-level processing. The absence of interaction between target word frequency and distractor frequency in young adults suggests these variables operate at different processing stages (Sternberg, 1969). If target word frequency effects occur at lexical-level processing, distractor frequency effects more likely occur at non-lexical processing stages. According to the revised competition hypothesis (Roelofs, 2005), attentional modulation of distractor frequency would still occur at lexical-level processing, which is inconsistent with the observed lack of interaction. Dhooge, Baene, and Hartsuiker (2013) used ERP technology to show that the distractor frequency effect emerged in the time window after 420 ms post-picture onset, providing support for the REH. Therefore, integrating these findings, our results for young adults' distractor frequency effects favor the Response Exclusion Hypothesis.

The absence of distractor frequency effects in older adults across both experiments raises the question: Why does this effect disappear with age? General cognitive abilities such as inhibitory capacity and working memory span decline with age. Speech production abilities also deteriorate, with older adults showing longer picture naming latencies and more word retrieval failures or errors than young adults. Older adults can generally retrieve semantic information for target words but fail to retrieve or only partially retrieve phonological information (Fieder, Nickels, & Biedermann, 2014; Cleary, Konkel, Nomi, & McCabe, 2010). Difficulties in speech production may stem from two sources. First, general cognitive decline may impair the ability to exclude irrelevant information—older adults' poorer interference exclusion ability may lead to speech production deficits. The stop-signal task index reflects how quickly individuals can exclude responses, not absolute response speed (Shao et al., 2013). Older adults' weaker non-selective inhibition ability suggests they require more time to exclude distractors. Within the non-competitive theoretical framework, this prolonged exclusion time may prevent the distractor frequency difference from manifesting in response times. In older adults, high- and low-frequency distractors had minimal impact on response times for high- and medium-frequency target conditions, while for low-frequency targets, the difference was 13 ms but not statistically significant.

Second, word retrieval difficulties may stem from language-specific processing declines, such as the weakened semantic-phonological connections posited by the TDH. As noted, the TDH was developed within the competition hypothesis framework, which can explain distractor frequency effects when attentional modulation is added. Picture-word interference studies have found that phonologically related distractors produce significant phonological facilitation effects, indicating that older adults do process distractor characters and automatically activate their phonological representations. However, older adults show smaller phonological facilitation effects than young adults, suggesting weaker semantic-phonological connections (Yang & Zhang, 2015; He & Zhang, 2017). Research indicates that word frequency information may be extracted during phonological encoding (Miozzo & Caramazza, 2003; Kandel, Álvarez, & Vallée, 2006). Miozzo and Caramazza (2003) found no interaction between distractor frequency and semantic relatedness but a significant interaction with phonological relatedness, suggesting that distractor frequency effects occur at the phonological encoding stage. We propose that reduced phonological representation activation in older adults during phonological encoding may prevent them from extracting or activating frequency information for unrelated distractors. In summary, the disappearance of the distractor frequency effect has two causes: reduced non-selective inhibition ability and weakened phonological representation activation that prevents distractor frequency information from being activated.

Regression analysis further demonstrated that non-selective inhibition ability significantly predicted older adults' picture naming times, while the correlation was not significant in young adults. This indicates that non-selective inhibition ability affects older adults' picture naming processes but not young adults'. Shao et al. (2013) examined relationships between selective inhibition, non-selective inhibition, and picture naming latencies, finding that non-selective inhibition correlated with naming latencies but not with selective inhibition measures, suggesting these two inhibitory abilities independently affect picture naming. Peng et al. (2018) compared access and deletion functions of inhibition in young and older adults, finding that older adults' inhibitory deficits made them more susceptible to interference, hindering target word retrieval. Language processing and non-selective inhibition abilities mutually influence each other. Spaulding (2010) found that children with specific language impairment showed lower non-selective inhibition ability than typically developing children. Thus, our findings indicate that declines in non-selective inhibition ability affect language production speed.

The lack of significant correlation between non-selective inhibition ability and picture naming latencies in young adults may be due to our narrow age range and limited variation in naming latencies. Older adults' average naming latencies were 800 ms (Experiment 1) and 838 ms (Experiment 2), substantially longer than young adults' 677 ms (Experiment 1) and 740 ms (Experiment 2), likely reflecting both general cognitive declines (Schaie, 2000) and language production deficits (Burke et al., 1991). Although MoCA scores indicated normal cognitive function, this does not preclude influences from changes in general cognitive abilities (working memory, attention, motor execution) and language processing capacities (e.g., vocabulary size). Future research should examine how different inhibitory abilities (selective and non-selective) affect picture naming across the full adult lifespan (ages 18–80).

Correlations between stop-signal task response times and distractor frequency effect magnitude were not significant in either age group. This suggests that for unrelated distractors, non-selective inhibition ability affects high- and low-frequency distractors equivalently. Shao et al. (2013) found no significant correlation between non-selective inhibition ability and semantic interference magnitude, concluding that non-selective inhibition is indeed non-selective, affecting semantically related and unrelated distractors equally. Similarly, our study found that non-selective inhibition ability affected overall picture naming processes but not the magnitude of the distractor frequency effect.

5. Conclusion

Our findings demonstrate that target word frequency affects picture naming processes in both young and older adults, with faster production of high-frequency than low-frequency words. In the picture-word interference paradigm, distractor word frequency affects young adults' picture naming, producing a distractor frequency effect that likely occurs at the response exclusion stage and is not influenced by non-selective inhibition ability. In contrast, older adults showed no distractor frequency effect, possibly due to degraded phonological representations preventing them from utilizing distractor frequency information—supporting the transmission deficit hypothesis of cognitive aging in speech production. Non-selective inhibition ability affected older adults' picture naming latencies: weaker non-selective inhibition capacity led to longer naming times, indicating that declines in general cognitive abilities also impact language processing. Future research should examine how different inhibitory abilities (selective and non-selective) affect picture naming processes across the full adult lifespan (ages 18–80).

References

Burke, D. M., MacKay, D. G., Worthley, J. S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults? *Journal of Memory and Language*, 30(5), 542–579.

Burke, D.M., & Shafto, M. A. (2008). Aging and language production. *Current Directions in Psychological Science*, 13:21–24.

Castro, N., & James, L. E. (2014). Differences between young and older adults' spoken language production in descriptions of negative versus neutral pictures, *Aging, Neuropsychology, and Cognition*, 21(2), 222–238.

Cleary, A. M., Konkel, K. E., Nomi, J. S., & McCabe, D. P. (2010). Odor recognition without identification. *Memory & Cognition*, 38(4),

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.).

Hillsdale, NJ: Erlbaum.

Cutting, J. C., & Ferreira, V. S. (1999). Semantic and phonological information flow in the production lexicon. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 25(2), 318–344.

Dell' Acqua, R., Sessa, P., Peressotti, F., Mulatti, C., Navarrete, E., & Grainger, J. (2010). ERP evidence for ultra-fast semantic processing in the picture–word interference paradigm. *Frontiers in Psychology*, 1.

Dhooge, E., De Baene, W., & Hartsuiker, R. J. (2013). A late locus of the distractor frequency effect in picture–word interference: Evidence from event-related potentials. *Brain and language*, 124(3), 232–237.

Dhooge, E., & Hartsuiker, R. J. (2010). The distractor frequency effect in picture–word interference: Evidence for response exclusion. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36(4), 878–891.

Duncan, J. (2004). Selective attention in distributed brain areas. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 105–113). New York, NY: Guilford Press.

Fieder, N., Nickels, L., & Biedermann, B. (2014). Representation and processing of mass and count nouns: A review. *Frontiers in psychology*, 5.

Finkbeiner, M., & Caramazza, A. (2006). Now you see it, now you don' t: On turning semantic interference into facilitation in a Stroop-like task. *Cortex*, 42, 790–796.

Forstmann, B. U., Jahfari, S., Scholte, H. S., Wolfensteller, U., van den Wildenberg, W. P. M., & Ridderinkhof, K. R. (2008). Function and structure of the right inferior frontal cortex predict individual differences in response inhibition: A model-based approach. *Journal of Neuroscience*, 28, 9790–9796.

Glaser, W. R.& Düngelhoff, E.-J.(1984). The time course of picture-word interference. *Journal of Experimental Psychology: Human Perception and Performance*, 10, 640–654.

He, J. Y., & Zhang, Q. F. (2017). The temporal courses of word frequency effect and syllable frequency effect of Chinese handwritten production in the old: An ERP study. *Acta Psychologica Sinica*, 49(12), 1483–1493. [何洁莹, 张清芳. (2017). 老年人书写产生中词汇频率和音节频率效应的时间进程: ERP 研究. 心理学报, 49(12), 1483–1493]

Jescheniak, J. D., & Levelt, W. J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 20, 824–843.

Jescheniak, J. D., Meyer, A. S., & Levelt, W. J. M. (2003). Specific word frequency is not all that counts in speech production: Comments on Caramazza, Costa et al. (2001) and new experimental data. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29, 432–438.

Kandel, S., Álvarez, C., & Vallée, N. (2006). Syllables as processing units in handwriting production. *Journal of Experimental Psychology: Human Perception and Performance*, 32(1), 18-31.

Logan, G. D. (1994). On the ability to inhibit thought and action: a user's guide to the stop signal paradigm. In D. Dagenbach, & T.H.Carr, *Inhibitory processes in attention, memory, and language* (pp.184-239). San Diego: Academic Press.

MacKay, D. G. & Abrams, L. (1998). Age-linked declines in retrieving orthographic knowledge: Empirical, practical and theoretical implications. *Psychology and Ageing*, 13, 647-662.

MacKay, D. G., Abrams, L., & Pedroza, M. J. (1999). Aging on the input versus output side: Theoretical implications of age-linked asymmetries between detecting versus retrieving orthographic information. *Psychology and Aging*, 14, 3-17.

Mahon, B. Z., Costa, A., Peterson, R., Vargas, K. A., & Caramazza, A. (2007). Lexical selection is not by competition: A reinterpretation of semantic interference and facilitation effects in the picture word interference paradigm. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 33, 503-535.

Miozzo, M., & Caramazza, A. (2003). When more is less: A counterintuitive effect of distractor frequency in the picture-word interference paradigm. *Journal of Experimental Psychology: General*, 132(2), 228-252.

Mortensen, L., Meyer, A. S., & Humphreys, G. W. (2006). Age-related effects on speech production: A review. *Language and Cognition*, 21(1-3), 238-290.

Mulatti, C., & Coltheart, M. (2012). Picture-word interference and the response exclusion hypothesis. *Cortex*, 48, 363-372.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, 126, 220-246.

Peng, H. M., & Mao, X. F. (2018). Will the deficit in inhibition increase the rates of tip-of-the-tongue among the elderly? *Acta Psychologica Sinica*, 50(10), 1142-1150 [彭华茂，毛晓飞. (2018). 抑制对老年人舌尖现象的影响. 心理学报, 50(10), 1142-1150].

Protopapas, A., Archonti, A., & Skaloumbakas, C. (2007). Reading ability is negatively related to Stroop interference. *Cognitive Psychology*, 54, 251-282.

Roelofs, A. (2005). From Popper to Lakatos: A case for cumulative computational modeling. In A. Cutler (Ed.), *Twenty-first century psycholinguistics: Four cornerstones* (pp. 313-330). Hillsdale, NJ: LEA.

Roelofs, A., Piai, V., & Schriefers, H. (2011). Selective attention and distractor frequency in naming performance: Comment on Dhooge and Hartsuiker (2010). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 37, 1032-1038.

Schaie, K. W. (2000). The impact of longitudinal studies on understanding development from young adulthood to old age. *International Journal of Behavioral Development*, 24(3), 257-266.

Schriefers, H., Meyer, A. S., & Levelt, W. J. M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language*, 29, 86-102.

Shao, Z., Meyer, A. S., & Roelofs, A. (2013). Selective and nonselective inhibition of competitors in picture naming. *Memory & cognition*, 41(8), 1200-1211.

Sörös, P., Bose, A., Sokoloff, L. G., Graham, S. J., & Stuss, D. T. (2011). Age-related changes in the functional neuroanatomy of overt speech production. *Neurobiology of Aging*, 32(8), 1505-513.

Spaulding, T. J. (2010). Investigating mechanisms of suppression in preschool children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, 53, 725-738.

Starreveld, P. A., & La Heij, W. (1995). Semantic interference, orthographic facilitation, and their interaction in naming tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21(3), 686-698.

Starreveld, P. A., & La Heij, W. (1996). Time-course analysis of semantic and orthographic context effects in picture naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22(4), 896-918.

Stemberger, J. P., & Macwhitney, B. (1986) Form-oriented inflectional errors in language processing. *Cognitive Psychology*, 18, 329-354.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, 30, 276-315.

Snyder, P., & Lawson, S. (1993). Evaluating results using corrected and uncorrected effect size estimates. *Journal of Experimental Education*, 61, 334-349.

Verbruggen, F., Logan, G. D., & Stevens, M. A. (2008). STOP-IT: Windows executable software for the stop signal paradigm. *Behavior Research Methods*, 40, 479-483.

Yang Q., & Zhang Q. F. (2015). Aging of word frequency, syllable frequency and phonological facilitation effects in Chinese speech production. *Psychological Science*, 38(6), 1303-1310. [杨群, 张清芳. (2015). 口语产生中词频效应, 音节频率效应和语音促进效应的认知年老化. 心理科学, 38(6), 1303-1310.]

Zhang, Q., & Wang, C. (2014). Syllable frequency and word frequency effects in spoken and written word production in a non-alphabetic script. *Frontiers in Psychology*, 5.

Zhang Q. F. & Yang Y. F. (2003). The lexical access theory in speech production. *Advances in Psychological Science*, 11, 6-11. [张清芳, 杨玉芳. (2003). 言语产生中的词汇通达理论. 心理科学进展, 11, 6-11.]

Zhang, Q., Zhu, X, & Damian, M. F. (2018). Phonological activation of category coordinates in spoken word production: Evidence for cascaded processing in English but not in Mandarin. *Applied Psycholinguistics*, 1-26.

Zheng, H. M., Wen, Z. L., & Wu, Y. (2011). The appropriate effect sizes and their calculations in psychological research. *Advances in Psychological Science*, 19(12), 1868-1878. [郑昊敏, 温忠麟, 吴艳. (2011). 心理学常用效应量的选用与分析. 心理科学进展, 19(12), 1868-1878.]

Zhu, X., Damian, M. F., & Zhang, Q. (2015). Seriality of semantic and phonological processes during overt speech in Mandarin as revealed by event-related brain potentials. *Brain and language*, 144, 16-25.

Zhu, X., Zhang, Q., & Damian, M. F. (2016). Additivity of semantic and phonological effects: evidence from speech production in mandarin. *Quarterly Journal of Experimental Psychology*, 69(11), 2285-2304.

Note: Figure translations are in progress. See original paper for figures.