The Effects of Aging on Phonological and Semantic Competition During Lexical Access

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Normal aging has been shown to impact cognitive processes, including those necessary for lexical access. While there is previous research on semantic and lexical processing during lexical access, there is a limited body of research investigating how healthy aging impacts these processes specifically. The aim of this thesis project was to provide further insight into age-related changes in lexical access and compare these patterns to predictions made by two major theories of aging, the Inhibition Deficit Hypothesis (Hasher et al., 1991; Hasher & Zacks, 1988) and the Transmission Deficit Hypothesis (Burke et al., 1991; MacKay & Burke, 1990), to understand why age-related changes in processes required for lexical access may occur. The Visual World Paradigm was used to measure age-related changes in semantic and phonological processes. A group of 9 younger participants and 1 older participant completed a Visual World Paradigm (Cooper, 1974) task in which they heard a word and had to select the corresponding image on the computer. Trials consisted of a 4x4 grid with a target word (e.g., lime), a phonological competitor (e.g., lion), a semantic competitor (e.g., grapefruit), and an unrelated distractor (e.g., rock). Using an eye-tracker, data on the total time spent gazing at each competitor type was collected, analyzed, and compared descriptively between groups to understand semantic and phonologic activation patterns across the lifespan. Further statistically analysis was conducted on data from the younger participants to determine statistical significance of age-related changes in lexical access. Results from this thesis project suggest that younger adults experience similar amounts of activation across competitor types while older adults experience greater semantic activation than phonological activation. Given that the age-related changes in lexical processing experienced by older adults is likely asymmetrical, findings were most consistent with predictions made by the Transmission Deficit Hypothesis.

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Preface

I would like to acknowledge and give my sincerest thanks to my thesis supervisor, Dr. Mike Dickey. His mentorship, support, and guidance throughout this journey made this project possible. I would also like to extend my appreciation to Dr. Sarah Wallace and Dr. Erin Lundblom for being integral members of my thesis committee. Thank you to Dr. Mandy Hampton-Ray for taking the time to moderate my thesis defense.

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1.0 Introduction

The normal aging process has been suggested to impact cognitive processes in healthy adults. Many theories of aging implicate domain-general cognitive decline throughout the lifespan (see Shafto & Tyler, 2014, for summary and discussion). Yet unlike other cognitive systems, language systems in older adults required for lexical access and comprehension are relatively preserved across the lifespan (Shafto & Tyler, 2014). Despite this, there is evidence that the specific processes needed for lexical access may be affected by healthy aging (Diaz et al., 2016; Taylor & Burke, 2002; Zhuang et al., 2016).

Lexical access requires activation and priming of phonological and semantic knowledge (Taylor & Burke, 2002; Yee et al., 2008). Operating through a “cascade-like” system, word retrieval is achieved by initially mapping sounds to phonemes during phonological activation and subsequently mapping phonemes to meaning during semantic activation (Allopenna et al., 1998; Taylor & Burke, 2002; Yee et al., 2008). As phonological and semantic systems are activated, priming information from each subsystem interacts and competes with one another to eventually result in the retrieval of the appropriate word (Allopenna et al., 1998; Yee et al., 2008). Though most language processes remain relatively intact throughout the normal aging processes, current research provides conflicting evidence regarding age-related differences in semantic and phonological processes. For example, some findings suggest that older adults’ semantic processing may be less efficient or more prone to interference than younger adults’ (Taylor & Burke, 2002), whereas other results suggest that older adults’ semantic processing is preserved (Harel-Arbeli et al., 2021, Payne & Silcox, 2019). There is also evidence from language production suggesting that phonological processing may be negatively affected by aging; for example, older adults are slower to produce words than younger adults and experience more 'tip of the tongue' states (knowing what word they want to say but not being able to find the sounds to say it) (see Diaz, Johnson, Burke & Madden, 2014). It is not yet understood if aging affects phonological and semantic activation differently, and furthermore, the theoretical basis of these differences is even less known. The purpose of this study is to examine the age-related differences in language processing during lexical access and to identify a theory of aging that is most consistent with these differences.

This research aims to answer the following research questions. First, are there age-related differences in semantic and phonological processing during lexical access? If there are age-related differences in semantic processing, I would expect older adults to experience greater competition from semantically related words. Similarly, if there are age-related differences in phonological processing, I would expect older adults to experience greater competition from phonologically related words. Second, based on the answer to this question, are age-related differences in semantic and phonological processing more consistent with the Inhibitory Deficit Hypothesis (Hasher et al., 1991; Hasher & Zacks, 1988) versus the Transmission Deficit Hypothesis (MacKay, 1987; Burke et al., 1991; MacKay & Burke, 1990)? The Inhibitory Deficit Hypothesis (IDH) postulates that deficits in attention and inhibition are responsible for deficits in lexical access, as older adults' have more difficulty inhibiting irrelevant information (see Taylor & Burke, 2002; Harel-Arbeli et al., 2021, for summary and discussion). In contrast, the Transmission Deficit Hypothesis (TDH), which is based on the Node Structure Theory (NST), suggests that age-related deficits in lexical access are a result of weakened connections between related semantic, lexical, and phonological nodes (NST; MacKay, 1987) which leads to attenuated activation of knowledge (as described in Taylor & Burke, 2002, Diaz et al, 2016). I predict that, if asymmetrical age-related differences in semantic versus phonological processing are found, results will be more consistent with the Transmission Deficit Hypothesis (MacKay, 1987; Burke et al., 1991; MacKay & Burke, 1990). However, if age-related deficits in lexical access are consistent across competitor conditions, results will be more consistent with the Inhibition Deficit Hypothesis (Hasher & Zacks, 1998; Zacks & Hasher, 1994).

As background to this study, I will begin with a discussion of lexical access in healthy adults. This is to be explained via a discussion of lexical access broadly, followed by phonological processing, semantic processing, and the interactions between the two subsystems. This will be followed by the presentation of the currently known effects of normal aging on cognitive processes, the effects of normal aging on language processing systems, and a discussion of two theories of aging: the Transmission Deficit Hypothesis (Burke et al., 1991; MacKay, 1987; MacKay & Burke, 1990) and the Inhibition Deficit Hypothesis. (Hasher & Zacks, 1998; Zacks & Hasher, 1994). This will lead to the research questions and hypotheses for the current study, as well as the methodology to be used.

1.1 Lexical Access Background

1 will begin with a broad discussion of the neural and cognitive processes involved in lexical access. Cognitive models (as discussed later) posit that spreading activation of multiple candidates (i.e., phonological priming, semantic priming) result in continuous competition between candidates until a word is selected (Allopenna et al., 1998; Marlsen-Wilson, 1987; McClelland & Elman, 1986). These lexical selection processes rely heavily on the left inferior

frontal gyrus (IFG) (Yee et al., 2008; Zhuang et al., 2016;). Neural substrates of lexical access will be discussed in more depth in later sections of this paper.

To further understand lexical access, it is also essential to define associated terminology. To begin, *lexical access* is the cognitive language process for word retrieval that requires both activation of stored representations of lexicon and selected among potential lexical candidates (Yee et al., 2008). In other words, lexical access is the general term used to describe the process of word retrieval through activation and competition between semantic and phonological representations. *Phonological priming effects* refer to activation of phonological knowledge that is spread to phonemically related words during phonological processing (Allopenna et al., 1998). For instance, when the word "beaker" is presented, activation of the word "beetle" also occurs, as the words share the same lexical onset (Allopenna et al., 1998). Like phonological priming, s*emantic priming effects* refer to the activation of semantically related words to a target word (Heuttig & Altmann, 2005). For example, when the word "axe" is presented, activation of the word "screwdriver" will occur (Heuttig & Altmann, 2005).

1.1.2 Phonological Processing

Phonological processing, or the process in which phonemes are used to understand language, plays an integral role in lexical access (Wagner & Torgesen, 1987). Several studies have found that phonological processing involves continuous activation of words that share the phonemes that have been heard or read thus far (McClelland & Elman, 1986; Marlsen-Wilson, 1987), meaning the onset of a word (e.g., <u>bea</u>ker) activates a set of lexical candidates that share the same onset (e.g., <u>bee</u>tle) that continue to compete with one another until selection is finalized. Each additional phoneme that a listener hears eliminates phonological competitors, until only a single word is left. Against this background, I will discuss two salient studies that investigated the phonological processing system of adults.

Allopenna et al. (1998) investigated whether words that share both onsets (e.g., beaker and beetle) and rhymes (I.e., that have overlapping final phonemes: beaker and speaker) will be activated and compete with a target, as proposed by continuous activation models of phonological processing and lexical access (e.g., Marlsen-Wilson, 1987; McClelland & Elman, 1986). Using eye tracking, Allopenna and colleagues conducted two experiments. Experiment 1 explored the time course of cohort and rhyme activation, while Experiment 2 explored whether rhyme activation effects hold when the auditory stimulus contains only information from a word’s onset. Both experiments used eye tracking to measure phonological processing the same set of stimuli. Four stimulus sets were used: a *full competitor set* consisting of the target word, onset competitor, rhyme competitor, and unrelated distractor (e.g., beaker, beetle, speaker, carriage), an *onset competitor set* consisting of target word, onset competitor, and two unrelated distractors (e.g., beaker, beetle, carriage, parrot), a *rhyme competitor set* consisting of the target word, a rhyme competitor, and two unrelated distractors (e.g., beaker, speaker, carriage, parrot), and a *noncompetitor set* consisting of the target word and three unrelated distractors (e.g., beaker, carriage, parrot, dolphin). In these eye tracking studies, participants listened to words while gazing at a computer screen that showed pictures corresponding to the 4 words listed above. Participants were supposed to point to the image that matched the word they were hearing. The eye tracking system measured which images participants were gazing at while they listened to the word. Evidence that the onset and rhyme competitor words were activated came from participants’ gazes: for example, participants gazing not only at the target word ‘beaker’ but at the onset competitor ‘beetle’ after hearing ‘bea …'. Results from Experiment 1 revealed that people gazed at the target and onset competitors after hearing the beginning of the word (e.g., bea…) and the rhyme competitor after the rest of the word (e.g., "…eaker"). Additionally, there were more gazes towards the onset and rhyme competitors compared to the unrelated distractor. Results from Experiment 2 revealed a similar pattern. Allopenna et al. (1998) found that words that differ from the input word by more than one feature (i.e., rhyme competitors) compete for lexical access, which suggests that words that share sounds are activated and compete with one another during lexical access.

Expanding on these findings, Yee et al. (2008) set to examine phonological and semantic processing in people with Broca's and Wernicke's aphasia using eye tracking. In this section, I will focus on the experiment related to phonological processing. By investigating phonological processing in people with aphasia (PWA), Yee et al. (2008) intended to provide insight into the neural basis of lexical access, specifically regarding the roles of the frontal and temporal lobes during auditory processing and word retrieval. The researchers recruited 12 college-aged students, 12 older adults, and 11 individuals with aphasia. Each trial consisted of a picture of the target word (e.g., tuba), a phonological competitor that was related to the target word by the entire first syllable or the onset and vowel of syllable (e.g., tulip) and 2 unrelated distractors (e.g., olives). Yee et al. (2008) found that older adults and PWA fixated on words phonological competitors more than unrelated distractors, indicating that words that share onsets are activated during lexical access and compete with one another.

The findings from Allopenna et al. (1998) and Yee et al. (2008) provide substantial evidence that words with phonological similarity compete for lexical access. Additionally, this prior research provides an understanding of phonological priming effects, in that words that share phonological features (i.e., onset, rhyme competitors) are activated in response to the presentation of target word. Findings from both studies are consistent with models of continuous mapping

(Marlsen-Wilson, 1987; McClelland & Elman, 1986), which serves as critical evidence that auditory presentation of a word activates a set of lexically similar candidates that compete for recognition. These findings provide important background regarding phonological processing that the current study will be using to investigate age-related changes in phonological processing.

1.1.3 Semantic Processing

Similar to the discussion of phonological processing above, this section will describe key findings regarding semantic processing. Semantic processing is the mechanism in which phonemes are mapped to meaning (i.e., activation of semantic knowledge: Mathur et al., 2020). As for phonological processing, continuous mapping models postulate that semantically similar words are activated in response to auditory stimuli and continue to compete until selection is resolved (Marlsen-Wilson, 1987; McClelland & Elman, 1986). There have been several studies to date aimed towards understanding semantic processing and its contribution to lexical access.

Heuttig & Altmann (2005) investigated semantic competitor effects using the Visual World Paradigm (VWP; Allopenna.et al. 1998) They aimed to explore whether semantic priming effects held across items that were semantically related (i.e., that shared some properties or features) but not semantically associated (i.e., that did not co-occur often) in hopes of broadening our understanding of semantic processing. While previous studies, such as Yee & Sedivy (2001), found that adults are more likely to look at words that are semantically associated (e.g., lock, key: these two words co-occur often and are thus semantic associates of one another), Heuttig & Altmann (2005) examined whether these effects would apply to words that were *only* semantically related (e.g., trumpet, piano: these are both musical instruments, and therefore share some properties or features). Sixty native English speakers participated in an VWP experiment with three conditions: a *target condition* consisting of the target word (e.g., piano) and 3 unrelated distractors (e.g., goat, hammer, carrot), a *competitor condition* consisting of a semantically related competitor to the target (e.g., trumpet given target word piano), and 3 unrelated distractors (e.g., goat, hammer, carrot), and a *target and competitor condition* consisting of the target word (e.g. piano), a semantically-related competitor (e.g., trumpet), and 2 unrelated distractors (e.g., goat, hammer). For each trial and across each condition, experimental scenes were paired with a sentence that contained the target word. Heuttig & Altmann (2005) found that participants gazed longer at the semantically related competitor compared to unrelated to distractors, indicating that semantic priming effects hold across words that are semantically related. These data also yield critical evidence that visual attention can be directed towards semantically related competitors in the environment.

Yee & Sedivy (2006) also used eye tracking to investigate whether transient semantic activation could influence visual attention in the environment. That is, they examined whether words or images that are semantically related to an object were activated as the auditory stimulus of a word unfolds, and furthermore, whether these same semantic activation effects occur when an object that shares the same word-onset as the semantic competitor unfolds. Experiment 1 conditions were as follows: a *semantically related competitor condition* that consisted of the target word (e.g., lock), a semantically related competitor (e.g., key), and 2 semantically and phonologically unrelated competitors (e.g., deer, apple) and a *control condition* in which the same set of stimuli were used as in *the semantically related competitor condition* but with an unrelated distractor serving as the target word (e.g., deer as the target word). Experiment 2 conditions were as follows: a *semantic onset competitor condition* consisting of a target word (e.g., <u>lo</u>gs) that share word-onset with an unpictured object (e.g., <u>lo</u>ck), a semantic onset competitor (e.g., key) that is semantically related to the unpictured object, and an unrelated competitor (e.g., deer), as well as a *control condition* similar to Experiment 1, in which the same set of stimuli from the experimental condition are used, but the unrelated distractor serves as the target word (e.g., deer as the target). Results of the study indicated that, similarly to Heuttig & Altmann (2005), people were more likely to gaze at a semantically related word than to an unrelated distractor. However, Yee & Sedivy (2006) also found that words that share a semantic relation to an unpictured phonological competitor to the target word are also activated during lexical access. That is, participants looked at an image of a key when hearing 'logs'. These findings further support the notion that words with related meanings, as well with words with related meanings to phonological competitors, are activated and compete for selection during lexical access.

Several other have produced similar results through examining semantic processing using the VWP. For instance, Yee et al. (2008) found that older adults and PWA fixate on semantically related objects more than unrelated distractors, which is consistent with the findings previously discussed. Similar results were found in Harel-Arbeli et al. (2021) and Taylor & Burke (2002). Overall, prior research on semantic processing has promising implications for the investigation of semantic processing in the current study.

1.1.4 Interactions between Phonological and Semantic Processing

As shown in the evidence reviewed above, semantic and phonological processing (as demonstrated by semantic competition and phonological competition) both occur during lexical access. Even more, these processes also interact with one another during word comprehension and production. The interaction between phonological and semantic processing is an important component of current models of lexical access. These models also presume that lexical access takes place continuously. That is, as a word unfolds, a set of potential candidates are activated based on the sounds they share with a target word, and the listener continuously evaluates speech input until a resolution is reached (Allopenna et al., 1998; Marlsen-Wilson, 1987; McClelland & Elman, 1986). Following continuous mapping models, when a listener hears a polysyllabic word (e.g., beaker), I would expect activation of phonologically (e.g., beetle) and semantically (e.g., cup) similar words that compete for recognition as the word unfolds. Previously discussed findings from Allopenna et al. (1998) and Yee et al. (2006) corroborate this hypothesis.

Models of these processes assume that phonological and semantic processing interact with each during lexical access (Allopenna et al., 1998; Marlsen-Wilson, 1987; McClelland & Elman, 1986). That is, activated phonological representations activate associated semantic representations, and vice versa, Evidence consistent with this claim comes from Yee and Sedivy's (2006) Experiment 2 semantic onset competitor condition, which showed that listeners activated words that are semantically related to a phonological competitor to the target word: participants looked at an image of a key when hearing '<u>lo</u>gs,' because it is semantically related to the (unpictured) phonological competitor '<u>lo</u>cks'. One model that explains this interaction is Node Structure Theory (NST; MacKay, 1987). As described in Taylor & Burke (2002), NST states that "nodes" are representational units that are linked together. These nodes are activated through the spreading activation, or priming, of phonological and semantic priming. There are two directions in which language processing occurs: top-down and bottom up. *Top-down processing* is used for language production; nodes of the semantic system are activated

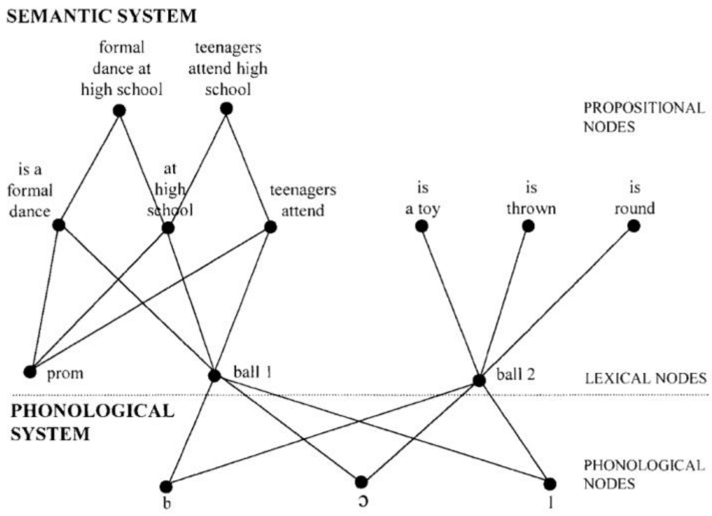


Figure 1

initially and eventually activation is spread to the phonological nodes to result in language production. For the purposes of this paper, I will focus more in-depth on bottom-up processing. *Bottom-up processing* is associated with word recognition; as a word is presented, nodes in the phonological system are activated and then eventually priming is spread to activate nodes in the semantic system. It is important to note that nodes from the phonological and semantic system are connected to one another. That is, activation of each system influences one another, as pictured in *Figure 1* (Taylor & Burke, 2002). *Figure 1* provides an example of processing pathways and connections. In this example, recognition of the word "ball" begins in the phonological system; each sound in the word is directly mapped to a node. Once phonological input has been mapped, priming is spread to the semantic system, where lexical nodes associated semantically to "ball" are either directly or indirectly activated. NST, as well as other connectionist models (e.g., McClelland & Elman, 1986), provide the framework for understanding lexical access and the interaction between phonological and semantic processing.

To summarize, lexical access has been shown to involve the activation phonological and semantic representations, which are connected to one another and interact over time. Lexical competitors are activated as the word unfolds, and connections between the phonological and semantic systems allow for priming to be spread until the listener eventually selects a word. This set of findings and models that explain them underline that disruptions how representations are activated and selected in the lexical system can greatly impact the listener's ability to appropriately recognize a word.

1.2 Aging and Lexical Access

Aging is associated with domain-general defects and changes in composition of white and grey matter in the brain (see Shafto & Tyler, 2014, for summary and discussion). The effects of aging on general language processes have been relatively well studied. Language processess have been found to remain relatively intact and stable throughout the aging process (Payne & Silcox, 2019; Shafto & Tyler, 2014). A systematic review by Payne & Silcox (2019) found that, although comprehension skills are essentially constant throughout the lifespan, older adults not only use context (the sentence or discourse preceding the lexical, visual, or other environment information) to support receptive language more extensively than younger adults but also recruit supplmentary neural networks to compensate for changes caused by domain-general age-related cognitive deficits. Though previous research has indicated that language remains relatively intact depsite normal aging, these findings suggest that older adults may experience be subtle changes in receptive language processing that have yet to be investigated.

1.2.1 Aging and Lexical Access

Though language has been found to remain relatively stable across the lifespan, some research has explored the impact of aging on lexical access. There is some evidence from language production suggesting that phonological processing may be negatively affected by aging (Diaz, Johnson Burke & Madden, 2014; Taylor & Burke, 2002). For example, older adults are slower to produce words than younger adults and experience more 'tip of the tongue' states (knowing what word they want to say but not being able to find the sounds to say it: see discussion Diaz et al., 2014). However, the focus of the current paper will be on language comprehension. Zhuang et al. (2016) investigated the neural substrates of receptive language and the consequences of aging on these structures. They recruited twenty healthy younger adults and twenty healthy older adults to participate in a behavioral task, as well as functional magnetic resonance imaging (fMRI). Three triad conditions were presented to both groups: a rhyme judgement condition with a cue word (e.g., blast), target word (e.g., passed), and an unrelated distractor (e.g., toast), a semantic similarity judgement condition with a cue word (e.g., crab), a target word (e.g., *shrimp*), an unrelated distractor (e.g., tears), and a perceptual similarity judgement that is not relevant to the purpose of this paper. Each triad was presented visually, and the participant was asked to determine which of the stimuli best matched the cue word. Age-related neural differences were tracked via participant fMRI. fMRI results indicated that older adults recruited the left inferior frontal gyrus (IFG) significantly more than younger adults in semantic tasks; behavioral tasks also showed that older adults performed with significantly greater accuracy during semantic tasks. These findings indicate that semantic processing is relatively preserved across the lifespan, but that older adults may activate some neural systems more than their younger peers during semantic processing. Notably, the region that older adults activated more strongly during semantic processing (left IFG) also appears to support resolving semantic competition during lexical access (Schnur et al., 2009; Thompson-Schill et al., 1997; Zhuang et al., 2006). This greater left IFG activation may represent a compensatory strategy that enabled older adults to have greater accuracy in the semantic tasks, as demonstrated in Zhuang et al. (2006). Interestingly, Zhuang and colleagues found that rhyme tasks were generally easier for both groups, resulting in similar response time and accuracy level. In rhyme judgement tasks, older and younger adults activated the bilateral IFG, bilateral supramarginal gyri, cingulate, and left superior temporal gyrus comparably. Findings from the rhyme tasks suggest that age-related differences in lexical access may only be apparent in more difficult semantic tasks relative to simpler rhyme tasks. Thus, results from Zhuang et al. (2016) insinuate age-related differences in semantic processing but not phonological processing during lexical comprehension.

Taylor & Burke (2002) aimed to study age-related changes in lexical access across two experiments. Although the focus of this study was on word production rather than word comprehension, Taylor and Burke’s findings are connected to the findings of Zhuang et al. (2016). In Experiment 1, 48 young adults (age 18-29 years) and 48 older adults (age 62-85) were asked to name pictures of objects with homophone or nonhomophone name while an auditory distractor was presented. The nonhomophone condition consisted of a target (e.g., <u>fr</u>og) presented with a semantic competitor (e.g., turtle), a phonological competitor (e.g., <u>fr</u>ost), or an unrelated distractor (e.g., lamp). The homophone condition consisted of a target (e.g., *ball*: the picture for this word was a toy, but ‘ball’ can also refer to a dance) presented with an appropriate-meaning homophone (e.g., *frisbee*: this competitor is semantically related to the depicted meaning of the target ‘ball’), an inappropriate-meaning homophone (e.g., *prom* this competitor is semantically related to the other, not pictured meaning of the target ‘ball’), and an unrelated distractor (e.g., hammer) with the intent to investigate semantic interference effects. These effects were measured when, "semantically related distractors preceded nonhomophone pictures and when appropriate-meaning distractors preceded homophone conditions" (Taylor & Burke, 2002). Results indicated that older adults showed greater semantic competition. Semantic distractors caused people to be slower to name the target picture than the unrelated distractor did in Experiment 1, and this slowdown was greater for older adults than it was for younger adults. However, phonological competitor effects were consistent between groups. Phonological distractors also caused people to be slower to name the target picture in Experiment 1, but this slowdown was no greater for older adults than for younger adults. Additionally, younger adults were quicker than older adults to name homophone pictures when they were preceded by inappropriate meaning distractor compared to an unrelated distractor, suggesting that older adults experienced more interference from this semantic distractor, even though it was not related to the meaning of 'ball' shown in the picture. These findings are consistent with those found in Zhuang et al., (2016): age-related differences in word retrieval are apparent in semantic tasks but not phonological tasks. Of note, Taylor and Burke also related results of Experiment 1 to theories of aging discussed later. Experiment 2 investigates these theories further.

Harel-Arbeli et al., (2021) employed online (eye tracking) and offline (behavioral) measures to investigate the effects of aging on semantic processing when presented with a spoken sentence. Thirty younger adults and thirty older adults were presented with four images on a computer screen. They then listened to a spoken sentence that either contained predictive information that would enable listeners to guess an upcoming target word (e.g., In winter, better take an umbrella*)* or did not contain predictive information (e.g., On the display, there is an image of a book). Of the predictive sentences, half contained competition trials in which two of the words could serve as the target word (e.g., umbrella, coat) while the other half did include a single correct target word. The researchers measured response accuracy, latency to touch response, and gazes towards target over the time course of sentence presentation. Offline measures did not indicate a significant age-related deficit resulting from semantic competitor effects. However, online measures did reveal a significant age-related difference in semantic processing: older adults were slower to gaze at the target in the semantic-competitor condition. Of note, semantic processing differences were only present in trials where context was presented with no competition. This effect indicates that when predictive context enabled listeners to activate two images which would be in competition during lexical access, older adults were slower to resolve this competition. This study is a particularly salient example of the importance of using online measures like eye tracking to measure age-related differences in lexical access. The differences found in interactions of the same tasks compared across online and offline measures suggest that there are early-stage age-related deficits in semantic processing which result in semantic competitors slowing activation of the target word.

Generally, language processes are thought to remain intact throughout the lifespan. However, results of Harel-Arbeli et al., (2021, Taylor & Burke (2002), and Zhuang et al., (2016) suggest that there may be more differences in receptive language between older and younger adults than previously thought. In using both behavioral and online measures to closely analyze and compare semantic and phonological processing in older versus younger adults, I hope that the current study bridges this knowledge gap.

1.3 Theories of Aging

In this section, I will focus on two cognitive aging theories that are commonly used to explain age-related differences in lexical access: the Inhibitory Deficit Hypothesis (Hasher & Zacks, 1998; Zacks & Hasher, 1994) and the Transmission Deficit Hypothesis (MacKay, 1987; Burke et al., 1991; MacKay & Burke, 1990). While the following two subsections explore these theories and their implications on age-related changes in lexical access in depth, a brief description of the predictions are as follows. The Inhibitory Deficit Hypothesis suggests that aging causes domain-general inhibition deficits that hinder older adults' ability to suppress irrelevant environmental stimuli. This failure to inhibit irrelevant stimuli may result over-activation of phonological and semantic competitors. The Inhibitory Deficit Hypothesis thus predicts overall deficits in lexical access with age, across semantic and phonological processing. Alternatively, the Transmission Deficit Hypothesis suggests that aging causes weakened connections between the nodes in semantic and phonological systems, which may lead to deficits in word recognition for older adults. Unlike the Inhibitory Deficit Hypothesis, the Transmission Deficit Hypothesis predicts that there may be asymmetrical age-related changes between the semantic and phonological systems.

1.3.1 Inhibitory Deficit Hypothesis

The Inhibitory Deficit Hypothesis (IDH) is a theory of aging that suggests age-related changes in language and lexical access are attributed to a deficiency in inhibition in old age (Hasher & Zacks, 1998; Zacks & Hasher, 1994). In other words, older adults are less able to inhibit attention to activated, yet extraneous, stimuli in the environment, leading to a decline in cognitivelinguistic function. Hasher et al. (1999) found that this inhibitory deficit leads to a larger impact of irrelevant environmental stimuli on older adults compared to younger adults. Additionally, Hasher et al. (1999) posits that spreading activation, or priming, of irrelevant environmental stimuli is broader in older adults, suggesting greater interference of these stimuli during lexical access. Under either of these views of activation and inhibition in aging, we would predict overall delays in lexical access in the presence of competition, regardless of competitor type (e.g., semantic or phonological), as the language system is grossly impacted by over-activation of competitors.

Recall Experiment 1 of Taylor and Burke (2002) in which the researchers investigated age-related differences in lexical access using a homophone and nonhomophone condition (refer to Section 1.2.1 for details of Experiment 1). In addition to the previously discussed findings, Taylor and Burke found that results of Experiment 1 were inconsistent with predictions made by the IDH. The findings indicated that older adults experienced greater semantic competition effects than younger adults; however, there were no significant differences between groups in the unrelated distractor condition. These results are inconsistent with the IDH older adults, who are assumed to be suffering global inhibitory deficits, and should therefore experience greater competition effects compared to younger adults, despite distractor type. Additional evidence against using the IDH to explain age-related differences in lexical access comes from Taylor and Burke's Experiment 1 findings. They found that when a target image was followed by an inappropriate meaning distractor (e.g., prom) younger but not older participants were quicker to name a picture of a homophone (e, g., toy *ball*) as compared to the unrelated distractor (e.g., hammer). These greater facilitation effects also appear to be inconsistent with the IDH's predictions, made by Hasher et al. (1999): we would have expected older adults to benefit from the inappropriate-meaning distractor because decreased inhibition of priming from the distractor word should result in overall greater semantic priming. Taylor and Burke (2002) further investigate the consistency between the IDH and age-related changes in lexical access in Experiment 2 of their study.

Experiment 2 of Taylor and Burke (2002) aimed to explained differences in competitor effects specifically in relation to the IDH and TDH In Experiment 2, the researchers used a picture-word interference task that paired a line-drawing (e.g., squirrel) with a distractor in each of the following conditions: *a semantic distractor* condition (e.g., mole), *a phonological distractor* condition (e.g., skate), a *semantic and phonological (S/P) distractor* condition (e.g., skunk), *an unrelated distractor* condition (e.g., lamp), and a *white noise* condition that was used to assess consistency with the IDH (i.e., older adults should have more difficulty inhibiting distraction from lexical competitor as compared to noise competitor). They found that picture-naming latency in the unrelated distractor versus white noise conditions was similar between older and younger adults; this is inconsistent with the IDH in that older adults should exhibit greater picture-naming latency with the unrelated distractor condition, as they should have more difficulty competition from any lexical competitor during lexical access. The same pattern of results was found when comparing picture-naming latency between a phonological distractor and white noise, further suggesting that results are inconsistent with the IDH as older adults should have shown greater competitor effects with a phonological distractor (particularly because the stimuli are perceptually similar in the phonological condition). Lastly, there was no significant difference in competitor effects in the semantically related or S/P condition which supports inconsistency with the IDH as older adults should have shown increase picture-naming latency in these conditions as compared to younger adults. This is because, under the IDH, older adults should have more difficulty with all lexical distractors due to inability to inhibit attention to extraneous stimuli (Hasher & Zacks, 1998; Zacks & Hasher, 1994). Overall, results of Taylor and Burke (2002) suggest that age-related changes in semantic and phonological processing *cannot* be explained using the Inhibitory Deficit Hypothesis.

As previously discussed, a study conducted by Harel-Arbeli et al. (2021) investigated the effects of aging on semantic competition using both online measures (eye-tracking) and offline measures (pointing to picture). They proposed that age-related changes in semantic processing *are* attributed to older adults' inhibitory deficits; this specific study aimed to determine whether inhibitory deficits appeared in early-stage word recognition, during word recognition, or late-stage word recognition. The researchers argued that the results of the study (refer to *Section 1.3*) are consistent with the IDH; the delay in resolving competitor effects with context is attributed to older adults' inability to inhibit lexical competitors. It should be noted that inhibitory deficit effects were not seen in offline measures, which the authors use to claim that inhibitory deficit effects must occur in early-stage word recognition in which presence of a semantic competitor inhibits and slows activation of the target word, rather than late-stage where recognition in which presence of a semantic competitor slows response time. Of note, Harel-Arbeli et al.'s study did not compare the effects of having different types of distractors present (such as semantic vs. phonological distractors), so the study did not directly test the IDH's prediction that older adults would experience greater interference from both semantic and phonological distractors during lexical access.

The two studies discussed provide conflicting evidence about age-related differences in lexical access as explained by the Inhibitory Deficit Hypothesis. While Taylor & Burke (2002) propose that age-related differences in lexical access cannot be explaining using this theory, Harel-Arbeli et al. (2021) propose that age-related differences in semantic processing can be explained by an early-stage inhibitory deficit during word recognition. The current study aims to mitigate this conflict in evidence by providing further evidence either for or against use of the IDH to explain age-related changes in lexical access.

1.3.2 Transmission Deficit Hypothesis

The Transmission Deficit Hypothesis (TDH) explains age-related changes in lexical access as being due to disruptions in node connections seen in connectionist models (refer to *Section 1.1.4;* MacKay, 1987; Taylor & Burke, 2002). In this theory, word recognition is dependent on the transmission speed of activated information, the amount of priming that can be transmitted, and the strength of connections between nodes (Taylor & Burke, 2002). The more frequently a node is activated, the stronger the connection between nodes (Taylor & Burke, 2002). The TDH suggests that aging weakens connection strength which reduces the speed and amount of priming transferred between nodes (Taylor & Burke, 2002). The result of decreased activation between nodes in older adults' is a delay in lexical access (Burke et al., 1991; MacKay, 1987; MacKay & Burke, 1990).

Unlike the Inhibitory Deficit Hypothesis, the Transmission Deficit Hypothesis predicts asymmetrical age-related differences in phonological and semantic processing. *Figure 1* illustrates the differences in node connections in the semantic, or top-down processing, versus phonological, or bottom-up processing, systems (i.e., lexical nodes are interconnected, while phonological nodes are only connected via other lexical nodes). Interestingly, the TDH assumes that word recognition, as processed by the bottom-up system, is less susceptible to aging deficits. This is because multiple phonological nodes are activated at once and converge onto one lexical node, which will then transmit activation to relevant semantic nodes enabling lexical access (mapping from sound to meaning). In contrast, top-down processing requires information from a single lexical node to spread across multiple phonological nodes (Laver & Burke, 1993), meaning that if activation transmission between this lexical node and the phonological nodes is slowed, word production will be slowed.

As previously discussed, Experiment 1 of Taylor and Burke (2002) investigated age-related differences in semantic and phonological processing, which they then explained in relation to the IDH and TDH (refer to Section 1.2.1 for details of Experiment 1). While they found that age-related differences in lexical access were likely not attributable to the IDH (as discussed in the previous section), the researchers argue that the findings are instead in line with predictions made by the TDH. For one, younger adults, but not older adults, named a picture of a homophone (e.g., toy *ball*) more quickly following presentation of an inappropriate-meaning distractor (e.g., prom) as compared to an unrelated distractor (e.g., hammer). This finding is consistent with predictions made by the TDH because they replicate the results of a previous study by Cutting and Ferreira (1999) in which similar results were attributable to the age-related decreases in strength of transmission from top-down priming of semantic competitors to lexical nodes and then lexical nodes to phonological nodes in older adults. That is, older adults were not faster to name a homophone picture following an inappropriate meaning distractor as compared to an unrelated distractor because they did not have the facilitation effects from top-down semantic priming to phonological priming experienced by younger adults. Furthermore, Taylor and Burke (2002) found that there were no differences in phonological distractor competitor effects (e.g., distractor=frog, picture=frost) between younger and older adults, which is consistent with predictions made by the TDH. Because the TDH predicts that bottom-up phonological priming is less vulnerable to aging, I would expect to find no significant differences in competition effects across age groups when a phonological distractor is presented.

While results from Experiment 1 suggest that age-related differences in lexical access are consistent with the TDH, Taylor and Burke's Experiment 2 further investigated the relationship between the TDH and these differences. Recall that Experiment 2 of Taylor and Burke (2002) (see Section 1.3.1 for details of this experiment) found that younger adults showed less semantic competitor effects than older adults when the presentation of a picture (e.g., squirrel) followed presentation of a semantically and phonologically related distractor (e.g., skunk). They argue that this finding is consistent with predictions made by the TDH because if an S/P distractor is presented first, priming of semantically and phonologically related competitors to the distractor should facilitate greater semantic activation for the picture which results in increased strength of transmission from lexical to phonological nodes. However, older adults experience deficits from top-down priming and therefore do not benefit from semantic priming facilitation from the S/P distractor being presented prior to the picture. Further evidence for top-down age-related deficits rather than bottom-up age-related deficits is that age-related differences in processing were only found when a semantic component was present in the distractor condition; distractors that were only phonologically related to the picture did not result in differences in competition effects between groups. Additionally, if transmission deficits were apparent during bottom-up priming, the researchers would have expected to find no significant difference in competitor effects across ages in the S/P condition, as processing would start at phonological nodes which are less vulnerable to aging. It should be noted that when the S/P distractor was presented after the picture, phonological facilitation, but not semantic interference, was seen across both groups with phonologically related and semantically related distractors as compared to the unrelated distractor. Under the TDH, presence of phonological facilitation without semantic interference is expected when the presentation of the distractor follows presentation of a picture. However, there were significantly larger phonological facilitation effects seen in younger adults than in older adults when the picture is presented before the distractor, which was unexpected, given that phonological priming is predicted by the TDH to remain unchanged relatively unchanged cross the lifespan, and should therefore be comparable across age groups. The researchers argue that this surprising finding may be indicative of unanticipated age-related interactions between and semantic interference and phonological facilitation.

It appears aging effects on lexical access are best explained by the Transmission Deficit Hypothesis. As noted previously, limited research has been done to investigate the effects of aging on lexical access as predicted by the Transmission Deficit Hypothesis. Taylor & Burke (2002) provides preliminary evidence that age-related deficits in lexical access are best explained using this theory, as compared to the Inhibition Deficit Hypothesis (refer to *Section 1.3.1*). While Taylor & Burke (2002) did found differences in competitor effects during word recognition that can be explained using the TDH, it is important to note that they only employed off-line, behavioral tasks. Findings from studies of aging and lexical access that use eye tracking have been found to have higher sensitivity to these aging effects (Harel-Arbeli et al., 2021). Given that Taylor & Burke (2002) found an unexpected difference in competitor effects in the S/P condition across groups, there is reason to believe there that the impact of aging as explained by the TDH may be better studied using experimental methods that are more sensitive to moment-by-moment phonological and semantic processing.

1.4 Visual World Paradigm

One commonly used experimental method that has been shown to be highly sensitive to moment-by-moment processing is the Visual World Paradigm. Several of the studies described above have used versions of the Visual World Paradigm to investigate language processing (e.g., Allopenna et al., 1998; Harel-Arbeli et al., 2021; Yee et al., 2008). Demonstrated first by Cooper (1974), the Visual World Paradigm (VWP) is an experimental paradigm in which the production of a spoken word results in eye gazes toward visual images that are related to the target word in some aspect. The duration, frequency, and time courses of eye gazes towards pictures reflecting spoken language are tracked in real time to investigate specific language processes, such as phonological and semantic processing (Allopenna et al, 1998; Cooper et al., 1974; Heuttig & Altman, 2005; Yee et al., 2008). For instance, Allopenna et al., (1998) employed the VWP to investigate phonological processing in healthy adults, while Heuttig & Altmann (2005) employed the VWP to semantic processing in healthy adults. This remainder of this section will focus on the structure of the VWP.

Cooper (1974) used the VWP to examine the degree to which the meaning of spoken language controls the locus of eye fixation. Cooper (1974) proposed that the VWP could determine whether the visual field of an individual is determined by the unfolding interpretation of language over time. The VWP consisted of 4 slides; each were divided into a 3x3 matrix and contained 9 pictures total. The pictures on a slide corresponded with a spoken narrative, and the pictures from each trial were related to the spoken narrative in one of four ways: 1) direct contextual that consisted of an exact representation of the corresponding spoken word by readily apparent association after taking into consideration the previous verbal context (e.g., the words she and herself when the previous picture was a queen), 2) indirect contextual that consisted of a closely related to the corresponding word that considers previous verbal output (e.g., in the sentence *"The queen was in agony"*, agony is indirectly and contextually related to a picture of the queen) 3) direct noncontextual consisting of an exact representation of the corresponding spoken word that considers previous verbal output (e.g., story about a dog is directly and noncontextually related to a picture of an anonymous dog), and 4) indirect noncontextual consisting of a representation closely related to the corresponding word by readily apparent association (e.g., the word lake is indirectly and noncontextually related to a picture of a sailboat). Using an eye-tracker, frequency of gazes and latency responses towards visual stimuli were recorded as the spoken language stimuli continuously unfolded over time. Results of the study supported the main hypothesis that individuals tend to spontaneously direct eye gazes towards visual stimuli in their direct environment that relate to the continuous interpretation of spoken language. Additionally, the VWP was successful in measuring language processes as they unfold overtime. Cooper (1974) provided pivotal data implicating direct investigation of specific language processes in real time.

1.5 Research Questions and Hypotheses

The purpose of this study is to examine the age-related differences in language processing during lexical access by using data from younger adults and comparing it to case studies of older adults and to identify a theory of aging that is most consistent with these differences. This research aims to answer the following questions:

1. Are there age-related differences in semantic and phonological processing during lexical access?

If there are age-related differences in semantic processing, I would expect older adults to gaze at semantic competitors for longer than younger adults. Similarly, if there are age-related differences in phonological processing, I would expect older adults to gaze at phonological competitors for longer than younger adults.

2. If age-related changes in semantic and phonological processing are present, are dthese changes more consistent with the Inhibitory Deficit Hypothesis (Hasher et al., 1991; Hasher & Zacks, 1988) versus the Transmission Deficit Hypothesis (Burke et al., 1991; MacKay & Burke, 1990)?

If there are predicted asymmetrical age-related differences in semantic versus phonological processing, results of the study will be more consistent with the Transmission Deficit Hypothesis. However, if age-related deficits in lexical access are predicted to be consistent across competitor conditions, results will be more consistent with the Inhibition Deficit Hypothesis.

2.0 Methods

2.1 Participants

Two groups of participants were recruited for this study: younger adults (ages 18-30) and older adults (ages 60-80). These age ranges were selected based on a similar study completed by Harel-Arbeli et al., 2021. 9 younger adults (8 females, 1 male; mean age= 23.33) and 1 older adult (female; age= 62) participated. Participants recruited from Pittsburgh, PA and the greater Pittsburgh area via recruited via word-of-mouth. Participation in this project was entirely voluntary. Inclusion criteria included: native English speaker, have normal or corrected vision and hearing, and the ability to tolerate extended periods of looking at a screen. Furthermore, participants may not have a history of neurological, cognitive, neuropsychiatric, or intellectual disabilities or disorder. All screened participants had normal hearing status. All the participants that were screened passed all screening measures and participated in the study in its entirety. Screening measures are discussed in *Section 2.3*.

2.2 Stimuli

There were 60 trials. Each trial consisted of the following organized in a 4x4 grid in the center of the screen: target word (e.g., lemon), a phonologically related competitor (e.g., lion), a semantically related competitor (e.g., grapefruit), and an unrelated distractor (e.g., rock) (Figure 2). Picture stimuli were naturalistic, full color photos taken from publicly available image sources (e.g., google images, CC BY license) trimmed to 240 x 360 pixels. All target stimuli were drawn from a battery of 325 picturable objects with name agreement of 85% or greater. Semantic, phonological, and unrelated distractor images were taken from the same public image sources and had comparable name agreement. All auditory stimuli were recorded by male native speaker of American English and measured for duration in Audacity. The order of trials and position of each stimulus on the grid was randomized across trials. These stimuli were all taken from an existing study of lexical access being conducted at VA Pittsburgh as part of a clinical trial of the efficacy of Semantic Feature Analysis (Boyle & Coelho, 1995).

Each trial began with presentation of the picture stimuli, immediately followed by presentation of a cross in the center of the screen. This fixation cross was intended to draw participants' attention to the center of the screen. Participants were required to gaze at the cross for 200 milliseconds for the auditory stimulus to be presented. The auditory stimulus was presented 1000 milliseconds following visual stimuli presentation.

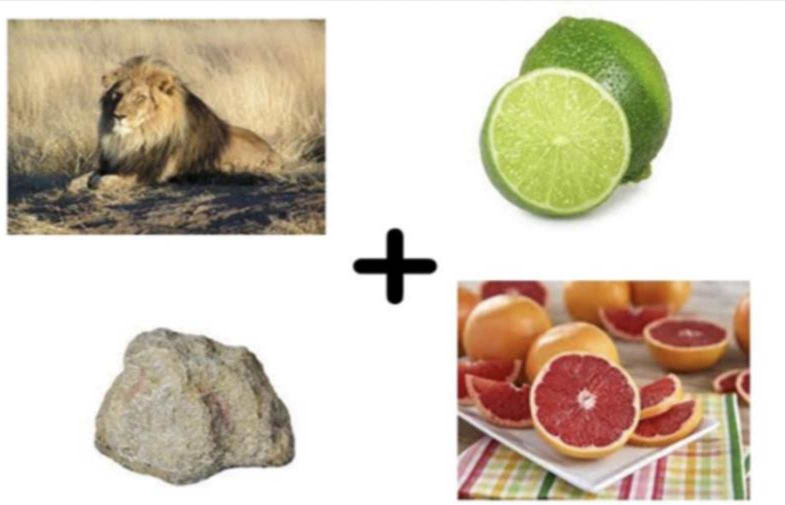


Figure 2

2.3 Procedures

All procedures were administered by the Principal Investigator (Rosenberg) and Co-Investigator (Mocevic) under the supervision of Dr. Mike Dickey. All procedures took place in the Brain and Communication Science Research Initiative (BASRI) laboratory space located in Forbes Tower on the University of Pittsburgh campus.

Upon arrival, all participants were given a copy of the “Informed Consent” document. The investigators thoroughly discussed all portions of the consent document and provided ample time for questions and clarification. Once consent was obtained, the screening measures commenced. For screening measures, participants completed a self-report screening questionnaires to assess their eligibility for study participation. A review of participant demographic information and speech-language history was collected. The following information was recorded: date of birth, sex/gender, years of education, race/ethnicity, native language, hearing and vision status, and self-reported history of speech-language conditions and other neurological, neuropsychological, and neuropsychiatric conditions. This information was used ensure that all participants did not have any conditions that would exclude them from participating in the research study. Participants with corrected vision and/or hearing were asked to self-report updated hearing status. Following screening procedures. Furthermore, all participants had to pass a pure-tone hearing screen binaurally. The participants underwent a pure-tone hearing screening at 500, 1000, and 2000 Hz at 25 dBHL, and 4000 Hz at 40 dBHL to ensure the adequate hearing ability. For the duration of the hearing screening, participants were asked to wear a set of over the ear headphones and to raise a hand whenever they hear a sound beep. It was unimportant which hand is raised.

If the participant passed the screening processes, they were asked complete tasks on a computer. These tasks took approximately 30 minutes. The computer tasks involved listening to a series of words and selecting a target word on a computer screen. Using an Eyelink 1000 eye tracking system, a video camera (placed below the computer screen) recorded participants' eye gaze while they listen to spoken words and look at displays of semantically or phonologically related or unrelated images. Spoken words were be presented via loudspeakers. Participants responded by clicking on an image on the screen that corresponds with the presented word. The time they spend gazing at different images on the computer screen was collected and later analyzed.

2.4 Instrumentation

Participants will be seated approximately 60 cm away from a 36-inch computer monitor with a resolution of 1440 x 900 pixels. Visual stimuli were presented using Experiment Builder v 2.3.38 software. To track gazes towards objects, a remote Eyelink 1000 eye-tracker camera was placed on a tabletop underneath the computer screen to record participants' left eye position at 2000 Hz. The eye-tracker was placed below the computer screen. Exact positioning of the eye-tracker in relation to the participant was dependent on participant factors (e.g., height) and was adjusted as such. Auditory stimuli were contained on an ASIO soundcard and presented through ASIO speakers at a standard volume of 50 dB SPL. Participants heard the auditory stimuli directly through the speakers; no headphones were used.

2.5 Data Analysis and Statistics

To determine the sample size, an a priori power analysis was carried out in G* Power (Faul et al., 2009) using data from a similar VWP study conducted by Harel-Arbeli et al. (2021). Harel-Arbeli and colleagues found a reliable interaction of age group (younger vs. older adults) and object fixated (target vs. distractor) for gaze patterns following presentation of the target word, indicating that there were fewer gazes towards the target (stronger competitor effects) for older adults compared to younger adults. The effect size was small to medium (partial eta squared= .117, Cohen's f= .364). For the current study, I assumed a conservative estimate of the size of the interaction (25% of Harel-Arbeli et al. (2021): partial eta= .029, Cohen's f= .174) and a medium correlation between repeated measures (.5). The power analysis suggested that 22 participants will be needed for each group (younger vs. older) adults to obtain .95 power. Adjusting for an assumed attrition rate of approximately 10%, we planned to recruit 25 participants per group. However, given time constraints and participant recruitment difficulties, the sample size obtained for both groups were inadequate to use this statistical analysis approach.

All data were collected via Eyelink1000. The initial data analysis plan was to run a Growth Curve Analysis to analyze the gaze data (Mirman, 2016). Growth curve analyses (GCA) examine the changes in gazes to images over time (for example, their level and slope) and how those changes are affected by variables like age group (young vs. old) or stimulus type (phonological, semantic, or unrelated distractor). However, the data analysis process adopted here used a different analysis plan than originally indicated. Rather than looking at how gazes at target change over time (i.e., GCA), data analyses looked at the cumulative time spent looking at each competitor type in each trial. This method of data analyses measures the amount of activation, or competition from, these semantic and phonological distractors. Descriptive data were analyzed via PivotTables on Microsoft Excel. For the younger participants, the total number of milliseconds spent gazing at each competitor type over the course of a given trial was averaged and compared to one another. For the older participant, the total number of milliseconds spent gazing at each competitor type over the course of a given trial was directly compared to one another.

Further statistical analyses were conducted on the data from the younger participants to determine if there was statistical significance in differences between distractor types. Using R software, a mixed effect regression model was used to predict the amount of time spent gazing at each competitor based on the type of competitor. The independent variable was competitor type; the dependent variable was the amount of time spent gazing at each competitor in a given trial. This model controlled for random effects in differences across participants; however, random effects of differences across items could not be controlled for given limited data. The cumulative number of milliseconds spent gazing at phonological competitors and semantic competitor were compared to the cumulative number of milliseconds spent gazing at the unrelated distractors in each trial. An additional analysis was run that looked at the cumulative number of milliseconds spent gazing at phonological competitors as compared to semantic competitors in a given trial. In this model, data from both descriptive analyses of the older participant's data and statistical analyses of the younger participants' data were used to examine whether there are age-related differences in phonological and semantic processing. The same set of data was used to determine whether age-related changes in lexical access are more consistent with the Inhibition Deficit Hypothesis (Hasher et al., 1991; Hasher & Zacks, 1988) or the Transmission Deficit Hypothesis (Burke et al., 1991; MacKay & Burke, 1990).

3.0 Results

3.1 Younger Participants

Descriptive data analyses conducted via PivotTables on Microsoft Excel suggest that younger adults spent, on average, a similar amount of time gazing at semantic, phonological, and unrelated competitors during each trial. Figure 3 represents the average number of milliseconds spent gazing at each competitor type in each trial. The average amount of time spent gazing at the unrelated distractor in each trial was 155.9356 milliseconds ($m_{unrelated}$=159.9356 ms; range: 0- 1,017 ms). The average amount of time spent gazing at the phonological competitor in each trial was 151.4261 milliseconds ($m_{phonological}$=151.4261 ms; range: 0- 2,053 ms). Finally, the average amount of time spent gazing at the semantic competitor in each trial was 143.3371 millisleconds ($m_{semantic}$=143.3371 ms; range: 0- 1,127 ms).

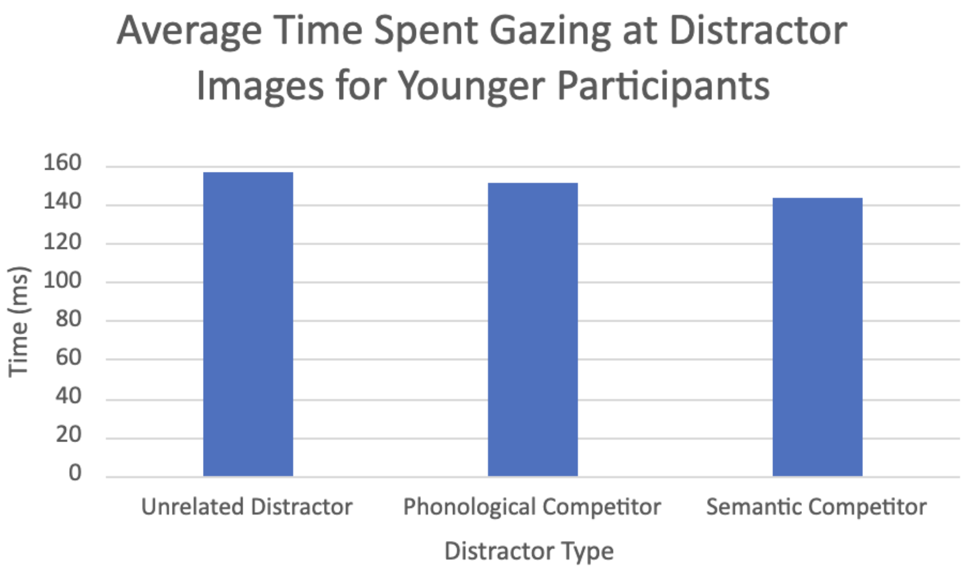
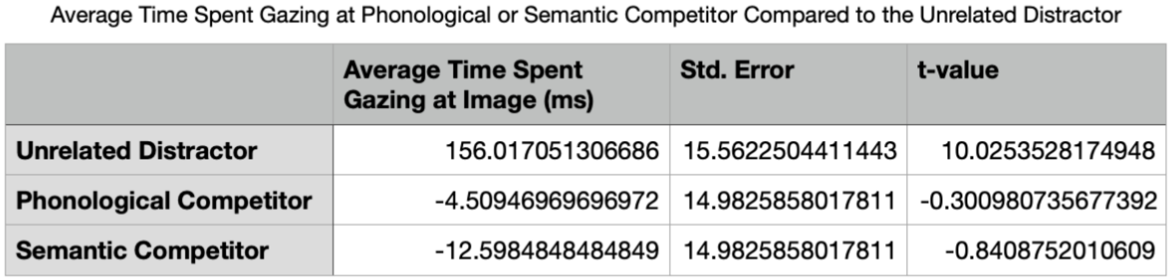


Figure 3

Statistical analysis using the mixed effect regression model yielded information regarding the statistical significance of differences between the cumulative time spent gazing at each distractor type. Table 1 reports model estimates and t values testing the statistical differences between average total time spent gazing at either the phonological competitor or semantic competitor as compared to the unrelated distractor. Negative values indicate that less time was spent gazing at either the phonological or semantic competitor compared to the unrelated distractor; positive values indicate that more time was spent gazing at their competitor type compared to the unrelated distractor. In each trial, younger adults spent an average of 156.02 milliseconds gazing at the unrelated distractor (standard error=15.56). They spent an average of 151.51 milliseconds gazing at the phonological competitor as compared to the unrelated distractor (average time spent gazing at unrelated distractor – average time spent gazing phonological competitor) in each trial. Comparison of gazes and the phonological and semantic competitors (see Table 1) yielded a t-value of -0.300 for the phonological competitor, indicating no statistical significance in cumulative time spent gazing at the unrelated distractor compared to the phonological competitor (cutoff for statistical significance: t ≥ +2.00 or t ≤ -2.00). Comparing total time gazing at the unrelated distractor versus the semantic competitor, younger adults spent an average of 143.42 milliseconds gazing at the semantic competitor as compared to the unrelated distractor (average time spent gazing at unrelated distractor – average time spent gazing semantic competitor) in each trial. This comparison (Table 1) yielded a t-value of -0.84 for the semantic competitor, indicating no statistical significance in cumulative time spent gazing at the unrelated distractor compared to the semantic competitor (cutoff for statistical significance: t ≥ 2.00 or t ≤ -2.00).

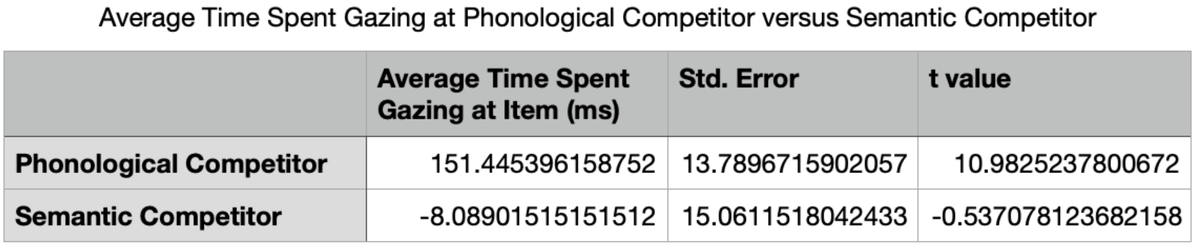


Average Time Spent Gazing at Phonological or Semantic Competitor Compared to the Unrelated Distractor

	Average Time Spent Gazing at Image (ms)	Std. Error	t-value
Unrelated Distractor	156.017051306686	15.5622504411443	10.0253528174948
Phonological Competitor	-4.50946969696972	14.9825858017811	-0.300980735677392
Semantic Competitor	-12.5984848484849	14.9825858017811	-0.8408752010609

Table 1

An additional analysis was conducted on a subset of the previous model to determine whether there was statistical significance in differences between average total time spent looking at the phonological competitor compared to the semantic competitor in each trial without consideration of the unrelated distractor (Table 2). Younger adults spent, on average, 151.45 milliseconds gazing at the phonological competitor in each trial. They spent an average of 143.56 milliseconds gazing at the semantic competitor compared to the phonological competitor (average time spent gazing at phonological competitor – average time spent gazing at semantic competitor) in each trial. This comparison yielded a t-value of -0.537 for the semantic competitor vs. the phonological competitor, indicating no statistically significant difference in time spent gazing at phonological versus semantic competitors in each trial (cutoff for statistical significance: $t \geq 2.00$ or $t \leq -2.00$).



Average Time Spent Gazing at Phonological Competitor versus Semantic Competitor

	Average Time Spent Gazing at Item (ms)	**Std. Error**	**t value**
Phonological Competitor	151.445396158752	13.7896715902057	10.9825237800672
Semantic Competitor	-8.08901515151512	15.0611518042433	-0.537078123682158

Table 2

3.2. Older Participant

Descriptive data analyses conducted via PivotTables on Microsoft Excel indicated that the single older participant spent varying amounts of time gazing at each competitor type. Figure 4 represents the average total milliseconds spent gazing at each competitor type in each trial. The average amount of time spent gazing at the unrelated distractor in each trial was 96.19643 milliseconds ($m_{unrelated}$=96.19643 ms; range: 0-1,086 ms). The average amount of time spent gazing at the phonological competitor in each trial was 0.428571 milliseconds ($m_{phonological}$=0.428571 ms; range: 0- 24 ms). Finally, the average amount of time spent gazing at the semantic competitor in each trial was 72.23214 milliseconds ($m_{semantic}$=72.23214 ms; range: 0-781 ms). Further statistical analysis was not able to be conducted given the limited data set for older adults.

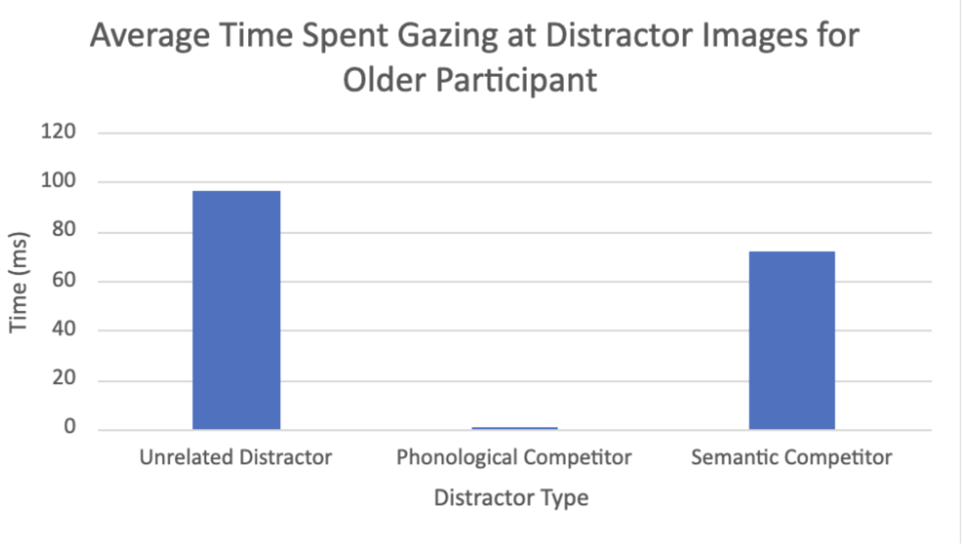


Figure 4

3.3 Aging Hypotheses and Consistency

The mean total time gazing at each competitor type in a given trial was compared between the younger participants and the older participant to determine if results were consistent with either the Inhibition Deficit Hypothesis (Hasher et al., 1991; Hasher & Zacks, 1988) or the Transmission Deficit Hypothesis (Burke et al., 1991; MacKay & Burke, 1990). Results of this comparison show that older participant spent less time gazing at all three competitor types (i.e., unrelated, phonological, and semantic competitors) as compared to the average of the younger adults (Figure 5, Table 3). Younger participants spent an average of 155.94 ms gazing at the unrelated distractor compared to the older participant, who spent an average of 96.19 ms gazing at the unrelated distractor. The average time spent gazing at the phonological competitor was 151.43 ms for younger participants versus 0.49 ms for the older participant. Finally, younger participants spent an average of 143.34 ms gazing at the semantic competitor, while the older participant spent an average of 72.23 ms gazing at the same competitor type.

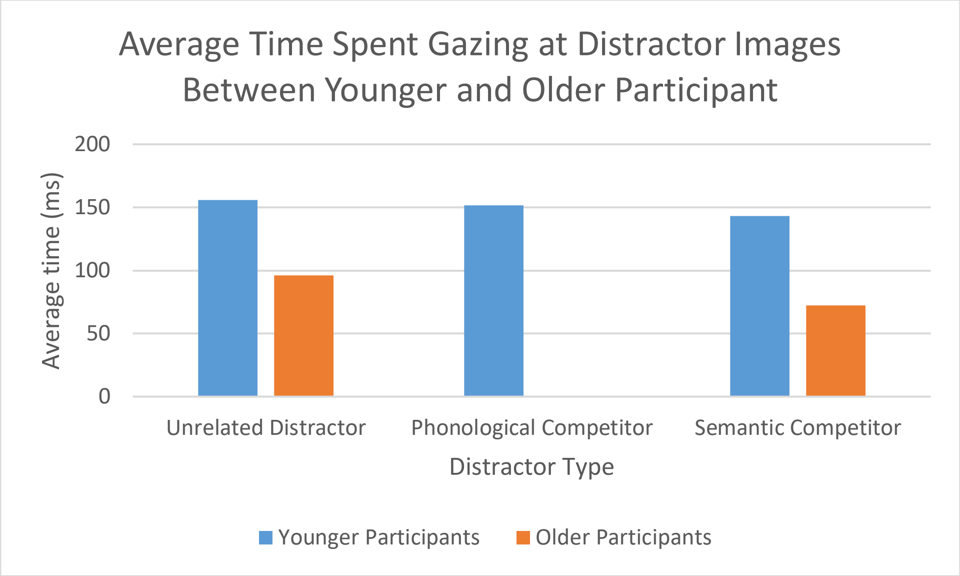
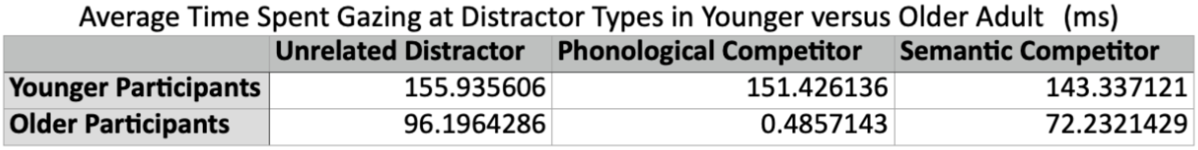


Figure 5



Average Time Spent Gazing at Distractor Types in Younger versus Older Adult (ms)

	Unrelated Distractor	**Phonological Competitor**	**Semantic Competitor**
Younger Participants	155.935606	151.426136	143.337121
Older Participants	96.1964286	0.4857143	72.2321429

Table 3

4.0 Discussion

Below I discuss the preliminary findings from this study. It is worth noting that findings for both research aims were not well powered given the limitations discussed below in *Section 5.1*. These findings are suggestive, rather than conclusive, of the effects of aging on semantic and phonological processing.

4.1 Age-Related Differences in Lexical Access

Preliminary results from this experiment suggest that younger adults spend a comparable amount of time gazing at both experimental competitor types (i.e., phonological and semantic competitors). This indicates that younger adults likely have similar activation of both phonological and semantic competitors in response to hearing a word. Interestingly, the results also suggested that younger adults spent a similar amount of time gazing at the unrelated distractor when compared to the phonological and semantic competitors, meaning that unrelated distractors were activated in comparable amounts to the experimental competitor types. Given results of prior studies on semantic and phonological processing (Allopenna et al., 1998; Marlsen-Wilson, 1987; McClelland & Elman, 1986; Taylor & Burke, 2002; Yee & Sedivy, 2006), it is unlikely these data suggest younger adults experience activation of their complete lexicon (semantically-related words, phonologically-related words, and all other words in person’s lexicon). Rather, reasons for this unexpected result may include instrument calibration differences and visual attractiveness of individual pictures on the screen. Visual stimuli that include background context and human figures (e.g., image of lion in jungle, image of human using a jackhammer) tend to attract more visual attention than isolated visual stimuli (e.g., image of a single lime with a white background, image of a single rock with a white background) (Theissen & Bassinger, 2022; Wilkinson & Light, 2011).

While younger adults appear to experience similar amounts of activation of both semantic and phonological competitors in response to an auditory stimulus, the older adult had a different pattern of activation. The older adult spent about 70 milliseconds more gazing at the semantic competitor compared to the phonological competitor. Additionally, the older adult experienced minimal activation of phonological competitors across trials. Though only one older adult participated in this thesis project, preliminary data suggest that older adults have greater activation of semantically-related words compared to phonologically-related words in response to hearing a word. These results are consistent with previous findings from Harel-Arbeli et al. (2021), Taylor & Burke (2002), and Zhuang et al. (2016) showing that older adults experience greater semantic competition compared to younger adults. Similar to younger adults, the data from the older adult show that the older adult spent the most time gazing at the unrelated distractor compared to both experimental competitor types. Instrument calibration difficulties and "attractiveness" of individual pictures on the screen may have contributed to this unexpected result from the older adult (Theissen & Bassinger, 2022; Wilkinson & Light, 2011); however, it is also possible that general cognitive decline (Shafto & Tyler, 2014), such as attention span, may have led to longer time spent gazing at unrelated distractors during each trial.

Overall, the preliminary results from this project may suggest that, while younger adults have a similar amount of activation of phonological and semantic competitors, older adults experience greater activation of semantic competitors compared to phonological competitors in response to hearing a word. In other words, while activation of semantic and phonological competitors during lexical access is similar in younger adults, healthy aging likely leads to a decrease in phonological competition compared to semantic competition.

4.2 Aging Hypothesis and Consistency

This thesis project aimed to further understand age-related changes in lexical access by comparing results with common theories of aging: Inhibitory Deficit Hypothesis (Hasher et al., 1991; Hasher & Zacks, 1988) and the Transmission Deficit Hypothesis (Burke et al., 1991; MacKay & Burke, 1990) to predict why aging may lead to these differences. Differences in amount of activation for all competitor types, though primarily the semantic and phonological competitors, were compared between groups to identify a pattern in age-related differences in lexical access. The results suggest that younger adults likely experience similar amounts of activation between phonological and semantic competitors while older adults likely experience more activation of semantic competitors versus phonological competitors. However, older adults still experience less activation of semantic competitors than their younger counterparts.

These results are most consistent with predictions made by the Transmission Deficit Hypothesis (Burke et al., 1991; MacKay & Burke, 1990). Using the TDH, I would expect to see asymmetrical differences in activation of lexical competitors between groups. More so, I would predict that, during lexical access, older adults experience greater semantic activation as compared to phonological activation (Taylor & Burke, 2002). Because results from this project indicate that older adults have more semantic competition than phonological competition *and* that these patterns are different than those seen in younger adults (i.e., similar amounts of competition between competitor types), they are most consistent with predictions made by the Transmission Deficit Hypothesis. These preliminary findings may suggest that older adults may experience age-related disruptions in node connections required for lexical access. It is important to note that the results do not align with the TDH's prediction that older adults will experience overall greater activation of competitors compared to younger adults. This discrepancy may be related to the limited sample size of both groups (particularly the older adult group); however, the influence of other age-related cognitive changes not within the scope of this project may also play a part (e.g., attention, memory) (Shafto & Tyler, 2014). Had the data suggested that older adults experience changes in semantic and phonological processing that are similar to one another, results of the study would have been more consistent with predictions made by the Inhibitory Deficit Hypothesis (IDH) (Harel-Arbeli et al., 2021; Hasher et al., 1991; Hasher & Zacks, 1988; Taylor & Burke, 2002). However, given that there were clear asymmetrical differences in semantic and phonological processing, age-related changes in lexical access are unlikely to be related to age-related inhibitory deficits. Overall, results of this study most closely align with predictions made by the Transmission Deficit Hypothesis.

5.0 Conclusions

Normal aging impacts cognitive functions, including lexical access (Diaz et al., 2016; Shafto & Tyler, 2014; Taylor & Burke, 2002; Zhuang et al., 2016). To date, there is little known regarding the impact of normal aging on lexical access in healthy adults. Previous research has indicated that semantic and phonological competitors are primed in response to an auditory stimulus. This phenomenon is studied via the Visual World Paradigm in which the production of a spoken word results in eye gazes toward visual images that are related to the target word in some aspect (i.e., semantic or phonological relatedness) (Cooper, 1974). These semantic and phonological competitors compete between themselves and one another during lexical access to eventually retrieve one word from the lexical system. Current research on the effects of aging on lexical access suggests that older adults experience greater competition between primed competitors than their younger counterparts. These changes are thought to be attributed to one of two main theories of aging: the Transmission Deficit Hypothesis (TDH) (Burke et al., 1991; MacKay & Burke, 1990) and the Inhibitory Deficit Hypothesis (IDH) (Hasher et al., 1991; Hasher & Zacks, 1988). Information gleaned from the preliminary results of this study intended to answer two main questions: 1) Are there age-related differences in semantic and phonological processing during lexical access? 2) If age-related changes in semantic and phonological processing are present, are these changes most consistent with the Inhibitory Deficit Hypothesis versus the Transmission Deficit Hypothesis? Results of the study suggest that are age-related changes in lexical access, which can be seen through the different amounts of activation of each competitor type experienced by each group. More specifically, younger adults experience similar levels of activation across competitor types, while older adults experience greater activation of semantic competitors compared to phonological competitors during lexical access. These results were most consistent with predictions made by the Transmission Deficit Hypothesis given that older adults have asymmetrical activation of semantic and phonological competitors during lexical access. This suggests that age-related changes in lexical access may be connected to disruptions in node connections necessary for lexical access that occur with healthy aging.

5.1 Limitations

There were several major limitations of this thesis project. Firstly, there was a limited sample size across both groups. A calculated sample size of 22 participants per group was necessary to obtain .95 power. Given time constraints, funding difficulties, and participant availability, data from only 9 younger participants and 1 older participant were able to be collected. Given the sizeable decrease in sample sizes across groups, data was not able to be compared statistically between groups. This hindered our ability to confidently determine differences in gaze patterns between younger and older participants. Rather, a less powerful set of analysis approaches (statistical analysis of data from younger participants using a mixed effect regression model and descriptive analysis and comparison of data from younger and older participants using PivotTables) was conducted. The statistical analysis method was modified to analyze total time spent gazing at each competitor type, rather than analyzing gaze patterns over time. Because of this, results are only suggestive of age-related changes in lexical access, as well as suggestive of consistency with theories of aging (IDH versus TDH).

Additional limitations of this project were the lack of consideration of participant education level, physical ability (e.g., manual dexterity), and prior speech and language impairments, as well as a lack of vision screening (participants self-reported vision status only). There was also a relatively homogenous sample of younger participants, use of a non-standardized set of images as stimuli, as well as intermittent equipment calibration difficulties. Equipment calibration difficulties included the need to override implemented equipment calibration and subsequent validation when eye tracker was having repeated trouble tracking the eyes. Overriding calibration and validation of eye gaze tracking reduces the integrity of the results for a given participant, as there is an increased chance that eye gazes are not being tracked reliably. For instance, when tracing the older participant's eyes, calibration and validation were bypassed because the eye tracker was having ongoing difficulty tracking gazes to the left quadrant. Inability to track gazes towards certain portions of the computer screen, as well as bypassed calibration and validation, may have led to skewed results (i.e., skewed data for gazes towards competitor type positioned in the quadrant that is being unreliably tracked).

Finally, visual stimuli included in trials were not normed across various factors (e.g., background, complexity, color). Previous research has shown that images with color, context, and human figures attract more visual attention than black and white images, images with no context, and images with abstract figures (Theissen & Bassinger, 2022; Wilkinson & Light, 2011).

5.2 Future Research

Given participant and recruitment limitations, future research should include a larger, more robust sample of younger and older participants. Sample sizes should be large enough to obtain statistically significant results. As there is still little known about the effects of normal aging on healthy adults, future research should investigate the effects of changes in specific cognitive processes, such as attention and executive functioning, on lexical access. There is also an opportunity to investigate the consistency between common models of aging and age-related changes in lexical access more deeply.

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